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COPPER RESOURCES OF THE WORLD

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FOREWORD

Although this volume is primarily concerned with the geologic environment of the known copper resources of the world, it has been thought that a clearer picture of these resources in their economic bearing could be presented by including a brief history of the development of the industry throughout the world, a discussion of the financial and economic factors of the industry, and an estimate of the amount of known reserves, with their geographic distribution.

Much of the geologic material has been contributed by official governmental agencies. Wherever possible the committee has solicited contributions from men personally familiar with the several districts, though naturally this has been possible for only part of the deposits. As a result a few districts have been described from secondary sources. Only a few copper-producing districts are omitted from the volume. The world's resources of copper are fairly comprehensively outlined here, although naturally it has been impossible to express accurately the total available reserves.

The technologic aspects of the copper industry have received little attention, although they are of controlling importance in the economic utilization of many of the deposits. Nevertheless it was decided to include a brief description of some of the mining methods employed in North America, as giving a picture of the current practice of a large and representative part of the copper industry.

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COPPER RESOURCES OF THE WORLD

INTRODUCTION

History of the development of the copper industry of the world

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General conditions

The tremendous acceleration in the growth of the world's demand for copper is clearly portrayed by the fact that of the world's total production in the last 100 years, nearly four-fifths was mined in the last 30 years and about one-third in the last 10 years.

The last century has witnessed the growth of the copper industry in the United States from its origin to a position of first importance in world production. Since 1840 the United States has produced 23,000,000 metric tons of the metal, or about 55 percent of the world's total of some 41,500,000 tons. Table 1 shows the relative standing of the five leading countries in copper production since 1800. The many changes that have taken place are significant. England, which stood first for the first half of the 19th century and supplied nearly 40 percent of the total in the next 30 years, dropped out of the picture entirely. For those 30 years, from 1850 to 1880, Chile ranked first, advancing from third place to contribute 37 percent of the total; in the next two decades Chile dropped back to third and in 1901–10 to fifth, but in 1911–20 it readvanced to third and in 1921–30 to second place, with 14.5 percent. The United States, starting in fifth place in the decade ending 1860, moved to third for the next two decades and then to first, where it has remained ever since. Russia, which ranked second to England until 1850, disappeared from the picture in the next 20 years. Spain and Portugal, taken together, appeared in fourth place in the decade 1850–60 and ranked second for the next four decades but since 1920 have passed from the picture. During the decade of the World War Japan occupied second place, rising from fourth, but then lapsed to its previous rank.

Africa was represented for the first time by the appearance of the Belgian Congo in third place in the last decade shown in the table. It is important to note that in 1932 Africa and Canada each produced more copper than Chile. This doubtless marks the beginning of a material change in the standing of the leading copper-producing areas of the world. Recent developments in those countries strongly indicate the approach of such a change.

TABLE 1.—*Principal copper-producing countries of the world, in the order of tonnage produced*

Period	World production (metric tons)	First rank: Country	First rank: Percent of world production	First rank: Average tenor of ore (percent)	Second rank: Country	Second rank: Percent of world production	Second rank: Average tenor of ore (percent)
1801–50	1,362,838	England	39.55	8.7	Russia	14.38	[a]10.2
1851–60	688,632	Chile	31.66	[a]20+	England	20.99	8.02
1861–70	1,042,678	Chile	43.56	[a]20+	England	11.33	7.4
1871–80	1,291,612	Chile	36.08	[a]20+	Spain and Portugal	15.41	3.2
1881–90	2,257,634	United States	32.33	[a]5.2	Spain and Portugal	21.75	3.2
1891–1900	3,764,268	United States	51.92	[a]3.8	Spain and Portugal	14.96	3
1901–10	6,920,379	United States	56.13	[b]2.06	Spain and Portugal	7.39	2.3
1911–20	11,056,283	United States	58.75	1.64	Japan	7.01	[a]4
1921–30	13,547,375	United States	52.30	1.49	Chile	14.50	[a]3

Period	World production (metric tons)	Third rank: Country	Third rank: Percent of world production	Third rank: Average tenor of ore (percent)	Fourth rank	Fifth rank
1801–50	1,362,838	Chile	14.17	[a]20+	Japan	Cuba.
1851–60	688,632	Russia	8.12	[a]10	Cuba	United States.
1861–70	1,042,678	United States	9.46	[a]8+	Spain and Portugal.	Russia.
1871–80	1,291,612	United States	14.66	[a]6.5	Germany	England.
1881–90	2,257,634	Chile	16.14	16	Germany	Japan.
1891–1900	3,764,268	Chile	6.27	8	Japan	Germany.
1901–10	6,920,379	Mexico	7.26	[a]6.5	Japan	Chile.
1911–20	11,056,283	Chile	6.20	[c]2.15	Mexico	Spain and Portugal.
1921–30	13,547,375	Belgian Congo	6.40	[a]3.6	Japan	Mexico.

[a] Estimated.
[b] 1906–10.
[c] Average Braden and Chuquicamata mines.

TABLE 2.—*Relation of United States copper prices to price index*

Period	Average price (cents per pound)	Commodity price index number [a] (1913=100)	Copper index number
1851–60	22.9	110.97	20.63
1861–70	29.2	168.1	17.37
1871–80	22.9	121.2	18.89
1881–90	14.8	91.4	16.19
1891–1900	12.4	73.1	16.96
1901–10	14.9	89.2	16.7
1911–20	18.8	138.8	13.54
1921–30	14.0	139.0	10.07

[a] From U. S. Department of Labor.

The reduction in the average grade of ore treated by the leading countries from 20 percent in 1851–60 to less than 1½ percent in 1914–30 shows plainly the tremendous improvement in mining and metallurgy during the last 70 years. Because of the inherently higher grade of the African deposits (in the Belgian

Congo and Rhodesia) and the Canadian deposits, this tendency in the average grade of all ore treated will soon be sharply checked if not reversed.

Table 2 shows the trend of prices for the metal in the United States by decades and the trend of relative prices as indicated by the copper index calculated from the general commodity price index. This again denotes the progress made in reducing costs in the face of tremendous reduction in the grade of ore treated.

Producing countries

United Kingdom

Notwithstanding the fact that copper has been produced in England for several centuries, not until 1826 did it become necessary to import copper in order to meet the demand for domestic consumption, as well as exports. The mining of copper in the United Kingdom was confined largely to Cornwall and Devon, 90 percent of the production being derived from these localities.

According to J. Percy (1), the dates of the opening of the smelters in Wales are as follows: Neath, 1584; Melincrethyn, 1695; Tailbach, 1727; Swansea, 1717; Penclawdd, 1800; Llanelly, 1805; Loaghor, 1809; Hafod, 1810; Cwmavan, 1837; Pembrey, 1846.

In 1860 the copper ore mined in the United Kingdom amounted to 368,499 metric tons, from which 16,223 metric tons of copper was obtained (2). That year was the peak for all known times. Since 1860 production from domestic mining has, broadly, steadily declined, and in 1931 only 67 tons was obtained.

In the years 1821–25 the mines of Cornwall and Devon produced 112,383 metric tons of ore with a copper content of 10,817 tons, and in this period no imports of ore were recorded. The amount of copper available for consumption in this 5-year period was thus apparently 2,163 tons a year. In 1931, 120,294 tons was available for consumption in Great Britain. As only 67 tons was produced from domestic sources in that year, the degree of dependence of the United Kingdom upon foreign copper is evident.

In the decade 1850–60 British capital developed mines in Chile, and for many years the production from these mines, combined with that from mines owned by Chileans, made Chile one of the major sources for the British requirements. Shortly before this decade production of copper had begun in the United States, but owing to the fact that there were no facilities for the handling of the ores, a large part of the copper then produced was shipped to Swansea, Wales, for reduction.

The Associated Copper Smelters had been formed at Swansea between 1830 and 1840. The object of this association was to control the copper market by keeping the buying prices of ore, matte, and blister low and the selling prices of the finished copper high. In the 20-year period 1881–1900 the smelting industry in the United States rapidly advanced, and by 1900 little if any copper was exported for refining.

In the 20 years 1891–1910 the commercial control of the Chilean copper mines changed, and with the development of the Chuquicamata, Andes, and Braden mines control of production passed into the hands of nationals of the United

States. Notwithstanding this change, Great Britain maintained through the London Metal Exchange its control of the international price of copper up to 1926. On the forming of the Copper Exporters, Inc., the copper market of the world was shifted to New York, where it remained to the end of 1932. After the liquidation of the Copper Exporters, Inc., the Ottawa economic conference of the British Empire in 1932 resulted in the acceptance of London as the point for establishing the world's price of copper.

In 1932, owing to the development of copper properties within the Empire and to the building up of a smelting and refining capacity sufficient to take care of the production of these mines, the British Empire is not only self-sufficient in its copper requirements but has a relatively large exportable surplus, which must find buyers in the international market.

Copper was for many years on the free list within the British Empire. One of the results of the Imperial Conference held at Ottawa in 1930 was the enactment of a resolution whereby all copper imported into the British Empire would be subject to a tariff of 2 pence a pound, and this tariff should remain in operation for 5 years provided that the demands of the copper industry were met by the domestic producers at a price not in excess of the world's price.

In the British Isles, in 1932, 7,500 metric tons of copper was produced, 149,189 tons imported, and 9,973 tons exported.

Chile

The copper industry of Chile is an ancient one. It is known that before the advent of the Conquistadores the aborigines worked some of the copper deposits. As the Spaniards were more interested in gold than in any other metal, nothing was done with the copper deposits until 1601. Then for many years only the high-grade carbonates and oxides were worked, and the ore was smelted in a primitive way in charcoal furnaces. In 1842 Lambert erected the first reverberatory furnace in Chile, and in 1857 the first blast furnace was installed. During the period 1801–50 Chile ranked third as a world producer of copper, but it was not until 1842 that mining in this country assumed much importance. From 1851 to 1880 Chile was the largest producer of copper in the world. In 1876 the production amounted to 47,165 tons of copper. In the following years the production rapidly declined, and for practically a quarter of a century it was maintained at a rate of about 25,000 tons a year. With the increased production from other sources throughout the world, Chile became a minor producer, ranging from third to fifth rank until the decade 1921–30, when Chile became the second largest producer in the world.

In the early days mining was confined to what might be termed the selective method, and the minimum grade that could be handled would be looked upon today as extremely high grade ore. In 1883 the average tenor of ore produced from 1,398 mines was 16 percent (3). As can be seen from table 1, the grade of the ore produced by Chile during 1911–20 was 2.15 percent; in 1921–30, 2 percent.

With the building of the cupola and reverberatory furnaces the shipments of ore decreased and those of copper bars and regulus increased; in 1879 the proportions were 80 percent for bar copper, 17.2 percent for regulus, and 2.7 percent for ore; in 1886, 92.92 percent for bar copper, 6.77 percent for regulus, and 0.31 percent for ore.

From 1850 until about 1900 the copper produced in Chile was largely controlled by wealthy families and English capitalists and was practically all shipped to England. Since 1900 by far the larger part of the production has come from the Andes, Chuquicamata, and Braden mines, which are commercially controlled by nationals of the United States. Most of the output of the Chuquicamata and Andes mines has been shipped to the United States, and the larger part of the Braden output has been sold in Europe. The potential output of these mines was estimated by Cates (4) as follows: Andes, 95,000 tons; Braden, 125,000 tons; Chuquicamata, 180,000 tons yearly.

During the entire history of copper production, with the exception of that mined by the aborigines, Chile has been an exporter of copper, practically all of its product being absorbed in the international markets. Owing to the cheapness with which the copper can be produced here, Chile's output is at present one of the major factors influencing the world's price of copper.

The import duty on copper in Chile is as follows:

	Pesos
Copper in ingots, per gross metric quintal	1.00
Copper in bars or sheets, per gross kilo	.20
Copper in bars or sheets, with designs obtained by means of the laminator, per gross kilo	1.50

In 1932, 97,516 metric tons was produced and 130,608 metric tons exported.

United States

Copper was first discovered in the United States in 1632, but not until 1705, when ore was mined at Granby, Connecticut, did it become an article of commerce. The occurrence of copper in the Lake Superior region was first brought to general attention in 1771 by Alexander Henry, a British subject. He began mining operations on the banks of the Ontonagon River near the present Victoria mine. Later the work was abandoned, and the real beginning of the copper industry did not take place until 1830, when Dr. Douglass Houghton, Michigan's first State geologist, visited the region. In 1841 Houghton published a report, and in 1844 the Federal Government began a combined land, geologic, and topographic survey. Mining permits were first issued by the Federal Government in 1844. The claims consisted of 9 square miles each but were soon reduced to 1 square mile, and a royalty of 20 percent gross was demanded by the Government. In 1846 the plan of permits was abolished, and all mineral lands were placed at a uniform price of $5 an acre, which was later reduced to $1.25 an acre (5).

In 1844 active mining was started at Copper Harbor, and in 1849 the Cliff mine paid the first dividend from this district. In 1883 the mines of Montana and Arizona became prominent, and in 1904 the so-called "porphyry copper" era began.

It may be noted from table 1 that in the decade 1851–60 the United States attained fifth rank among the copper producers of the world, and in the next

20 years it ranked third. From 1881 to 1930 it has been the world's greatest producer. Prior to 1883 by far the larger part of the United States production was derived from the Lake Superior region and the Appalachian area.

Copper was discovered in the mountains of eastern Tennessee in 1843. In 1847 the Hiwassee property, now known as the Burra Burra lode, produced 31,000 pounds of ore carrying 25 percent of copper. This ore was shipped to the Revere Smelting Works, near Boston. During the period from 1848 to 1854 ores were shipped from this district to Dalton, Georgia, and Cleveland, Tennessee, and thence forwarded to the Revere Smelting Works, to Swansea, Wales, and to other distant smelters. From 1855 to 1863 the ore was roasted and treated in charcoal-fuel furnaces, and late in the fifties a refining plant and wire and plate works were built at Cleveland, Tennessee. The furnaces used during this period had a daily capacity of 3 to 4 tons, and it was necessary to take five or six steps to obtain furnace-refined copper. From 1866 to 1878 the practice was essentially the same except that the furnaces were greatly enlarged. The period from 1892 to 1904 marked the development of the modern smelting practice. In the earlier stages mentioned the ores were heap roasted, but as the operations grew, the gases liberated caused many suits for damage. In 1904 heap roasting was discontinued, and the ores were treated by obtaining low-grade matte in the first process and high-grade matte in the second process. The matte is then converted to blister copper. Notwithstanding the attempts to do away with acid fumes it was not until 1903 that the manufacture of sulphuric acid was introduced.

In the Lake Superior copper ores the copper is found almost wholly in the metallic state. Smelting is therefore simple in principle, and the product is what is known as "furnace-refined." Where this material carries sufficient silver to make recovery of the silver commercial it is refined electrolytically. A large part of the ore of the Lake copper region contains arsenic. In some places the arsenic is eliminated by electrolytic refining, but of late years arsenical copper is produced as a furnace-refined product and is sold for special uses.

Butte, Montana, was discovered in 1864 and for a period was regarded as a gold-producing camp, though from 1865 to 1893 silver was the principal metal mined. The copper area was not developed until 1872. Thus the periods of copper and silver development overlapped. The first successful mining of copper ore was done by W. A. Clark (6) in 1878, and the ore at that time was hauled 400 miles in wagons to Corinne, Utah, and then shipped by rail to eastern smelters and to Swansea, Wales. Some idea of the importance of having a smelter situated in the Butte area may be obtained from the fact that in 1877 a shipment of copper ore to the smelting plant at Baltimore, Maryland, from the Green Mountain claim, containing 35 percent of copper (then worth 18⅝ cents a pound) and not less than $50 a ton in silver and gold, gave no profit to the shipper after mine, freight, and reduction costs were paid. Sometime after 1881 and prior to 1883 a shipment was made from the Anaconda shaft to Swansea, Wales, for reduction. In 1883 a smelting plant, destined to become one of the greatest in the world, was established near Anaconda on Warm Springs Creek. The production of Montana from 1845 to 1921 represented 27 percent of the total production of the United States. However, in 1913 Arizona became the greatest producer in the country.

The earliest mining of copper in Arizona was done at Morenci in 1873 by a Scotch company. For several years the high-grade copper ores were hauled by wagon to tidewater on the Gulf of California and shipped to Swansea, Wales. In September, 1874, the Copper Queen Co. started work at Bisbee, and since that time it has been in practically continuous operation. In the following year development took place in the Globe district and at Pinal. One of the factors retarding the development was the total lack of fuel for reduction of ore, and as late as 1880 English coke was utilized for this purpose.

In the early history of the mining of copper in the United States the high-grade ores were exported for treatment. Copper smelting was given an impetus in 1873 by the introduction of the water-jacket furnace, but it was not until 1890 that the United States smelting industry was built up to a point where it treated not only the domestic ore but the larger part of the ores imported from the west coast of South America. Since 1900 the refining capacity in the United States has been sufficient to take care of the copper imported from mines commercially controlled by nationals of the United States.

From the very earliest date of mining the United States has been an exporter of copper.

Table 3 shows the exports, imports, and production of copper for the particular years indicated, not the average of the decade.

TABLE 3.—*Copper exported, imported, and produced in the United States, 1900, 1910, 1920, and 1930, in metric tons*

Year	Exports	Imports	Production (smelter output)
1900	154,420	47,721	275,007
1910	306,766	155,448	490,091
1920	279,083	199,644	548,575
1930	412,441	370,579	632,663

Since 1927 the rapid development of the policy of national self-sufficiency has materially affected the world's flow of copper. In 1932 the production (smelter output) in the United States was 278,997 metric tons; the imports of unmanufactured copper were 177,854 metric tons; and the exports exclusive of insulated copper wire were 148,921 metric tons.

The international price of copper up to 1926 was established by the Metal Exchange of London, notwithstanding the fact that in 1870, when the United States occupied the third place among the world producers of copper, an attempt was made to control the price by what is known as the Lake pool, carried on by the then Calumet & Hecla Mining Co. In 1887 (at this time the United States was the largest producer of copper in the world) the Secretan Syndicate, in part a French organization, was formed to control stocks; and in 1899 the Amalgamated Copper Co., the forerunner of the Anaconda Copper Co. of Butte, was formed and made an unsuccessful attempt to control price. In 1921 the Copper Exporters' Association was organized in the United States, the object being to assist in the liquidation of the excess stocks then on hand. This corporation was the forerunner of the Copper Exporters, Inc., which was formed in 1926, and owing to its international character and to the fact that the United States in this period produced more than 52 percent of the world's total, the international price was fixed in New York for the next 6 years.

Prior to June, 1932, when a duty of 4 cents a pound was enacted, there has been only one period—from 1890 to 1894—when imported copper was dutiable. The following table shows copper prices at New York and London during the periods mentioned, under the various rates. The prices in the years immediately following the lifting of the tariff, which became inoperative in October, 1894, are given in order to illustrate the situation leading up to the attempted control of prices in 1899.

TABLE 4.—*Copper prices, 1890–99*

Year	Duty (cents a pound)	Copper prices (cents a pound) (7)		
		New York ("Lake")	London ("Best select")	Difference
1890: Jan.–Oct....	4	15.53	13.28	2.25
Nov.–Dec...	1¼	16.35	13.62	2.73
1891............	1¼	12.63	12.27	.36
1892............	1¼	11.55	10.87	.68
1893............	1¼	10.75	10.41	.34
1894: Jan.–Sept...	1¼	9.37	9.49	[a].12
Oct.–Dec...	None	9.74	9.64	.10
1895............	None	10.76	10.22	.54
1896............	None	10.88	11.14	.26
1897............	None	11.29	11.37	[a].08
1898............	None	12.03	12.01	.02
1899............	None	17.61	17.00	.61

[a] London price higher than New York price.

Russia

The copper industry of Russia has been carried on for a long period. As shown in table 1, from 1801 to 1850 Russia occupied second place as a world producer. In the next decade it receded to third place, in the decade 1861–70 it occupied the fifth place, and since that time it has been one of the minor producers of the world. Up to 1850 Russia was an exporter of copper, but for the next 30 years the production steadily declined and Russia became a relatively large importer, as the domestic production was only about three-fourths of the consumption. The industry was revived in 1906 by an import duty on all copper products. The imports consist almost entirely of electrolytic refined copper used for the electrical trades.

For almost 100 years prior to 1917 the larger part of the Russian copper industry was operated by British technical skill and investments. In the early days most of the copper produced was shipped to England for refining and fabrication. In 1907 a syndicate was formed, known as the Mjed, which absolutely controlled the copper industry until 1914. Under the present form of government the copper industry has been socialized. During the last few years every effort has been made to attain Russia's self-sufficiency. The accomplish-ment of this desire is well within the realms of possibility in that the reserves of Russia are adequate to take care of future demands.

Imports of copper ores are free of duty; there is a tariff of 50 percent ad valorem on unfabricated metals, which, on imports through Murmansk ports during the period between November 15 and April 14, is reduced to 44½ percent.

In 1932 about 32,000 metric tons of copper was produced and 11,948 metric tons imported.

Spain

The copper industry of Spain is centuries old, and practically from its very inception Spain has been an exporter of copper. Some idea as to the antiquity of this industry can be gleaned from the fact that the history of the Rio Tinto mines can be traced back for 30 centuries, to the time when the Phoenicians first colonized the coast of Huelva. Moreover, there is every probability that these deposits were operated by the early Iberians before the arrival of the Phoenicians. During the last 40 years the larger mines of Spain have been operated by British capital. There seems every evidence that there will be little change in the part played by Spain in the copper industry from that which has existed in the past. Spain is not only practically self-supporting for its copper requirements but has an exportable surplus.

Crude copper imports in Spain bear tariffs, in gold pesetas per 100 kilos net, as follows:

	First tariff	Second tariff
Copper matte	3.30	1.10
Cementation and scrap copper	5.50	1.65
Ingot and cathode copper, etc.	82.50	27.50

In 1932, 9,070 metric tons was produced, 225 metric tons imported, and 303 metric tons exported.

Japan

Copper mining in Japan dates back to the year 708, when copper was found in the Province of Fushashi. Early in the 15th century shipments of copper were made to China. An invoice under date of 1456 shows that 92 tons of copper was in one cargo. This was a rather large tonnage for the times. Prior to 1858 the Dutch had a considerable copper trade with Japan (8).

Modern smelting methods were introduced in Japan in 1890. Japan has largely followed the latest American practice in the handling of its copper ores. In 1912 Japan became the second largest producer of copper in the world, and the domestic copper industry was next in importance to that of petroleum. With the end of the World War and the decline in the price of copper, it became commercially more expedient for Japan to buy copper in the United States than to produce her own. The fabrication of copper in Japan was materially expanded during the war years, and in order to maintain this industry it was deemed wise to draw on supplies other than those found within the political confines of the Empire. There is little doubt that Japan could be at all times self-sufficient for its copper requirements. The fact that at times the imports are greater than the domestic production is a matter of national policy. All the copper mines of

Japan are state-owned, and the right to work them by individuals or companies is regulated by the state. Heretofore only Japanese nationals have been operators.

Copper ores (including those calcined), matte, bottom, and slag are free of duty on importation into Japan.

In 1932, 70,646 metric tons was produced, 296 metric tons imported, and 2,766 metric tons exported.

Mexico

The copper-mining industry of Mexico is a very old established business. The country has for many years been an important contributor to the world's commerce, but little of the copper produced is consumed domestically. In the decade 1901–10 Mexico was the third largest producer in the world, and the tenor of the ore mined was higher than in the countries occupying first and second places. By far the larger part of the production is controlled by nationals of the United States and of France. During the last few years heavy taxes, arbitrary scales of wages, and the possibility of confiscation by the Government have seriously retarded the advancement of the industry. The mines in the northern part of Mexico ship practically all of their product to the United States. For many years the Boleo mine, in Baja California, at the Port of Santa Rosalia, shipped its product to France, but of late the output has been sent to Tacoma, Washington, for refining.

Imports of crude copper in Mexico bear a duty of 0.09 peso per gross kilogram, to which a surtax of 3 percent is added.

In 1932, 39,825 metric tons was produced, and 34,055 metric tons exported.

Belgian Congo

The commercial development of copper in the Belgian Congo has been confined entirely to the 20th century. The only copper company operating in the country is the Union Minière du Haut Katanga (a Belgian company), and about one-third of its shares are held by an English company, the Tanganyika Concessions, Ltd. The Union Minière du Haut Katanga is a subsidiary of the Belgian Congo Concessions Co., and its operations form a part of the general colonization scheme of the Belgian Government.

The ore is smelted near Elizabethville, where furnace-refined and blister copper are produced. In 1911 the output of the smelter was 981 tons, and for a short time in 1931 the output was at the rate of 192,000 tons a year. Most of the copper is refined at Hoboken, Belgium, but a small portion of the output has been refined at Baltimore, Maryland. Practically all of the output is marketed in continental Europe.

In 1932, 54,000 metric tons (copper content, blister) was produced, and 56,630 metric tons exported.

Germany

In the decade 1891–1900 Germany was the fifth largest producer of copper in the world, but since then this country has contributed but a small percentage to the world's production. The copper industry of Germany is so closely allied with that of the Mansfeld Co. that the history of Mansfeld is the history of the German industry. Systematic mining was begun on the copper deposit at

Mansfeld in 1199, and in 1852 the company now working the deposit was formed by the consolidation of various interests. For many years practically the entire output of German domestic mines has been absorbed locally. Since 1930 the Mansfeld Co. has been subsidized by the Prussian Government in order to relieve the social strain that would be caused by the closing down of its mines. Germany is one of the largest purchasers of copper in the international market and has drawn a large part of its needs from the United States.

In 1912 the production of copper from native ores in Germany was 27,400 metric tons and the imports from the United States 98,852 tons. In 1929 the production was 53,589 tons and the imports from the United States 81,131 tons.

Copper is admitted duty-free into Germany.

In 1932, 50,900 metric tons was produced, 131,128 metric tons imported, and 44,801 metric tons exported.

Canada

During the last 10 years Canada has become a very important factor in the international trade in copper. The largest potential exporter is the International Nickel Co. The policy of the operating company is to govern the production of copper by the amount of nickel that can be sold. As the national requirements are relatively small, by far the larger part of Canada's production must find a market in international trade. Until 1920 most of Canada's copper output was refined in the United States. Since that time the refining capacity has been gradually increased, and it seems fair to assume that within a reasonably short time all the copper produced will be refined within the Dominion. The present production does not indicate the productive capacity, which may at present be assumed to be about 220,000 tons.

In 1932 approximately 32,000 metric tons was produced, 1,074 metric tons imported, and 58,148 metric tons exported.

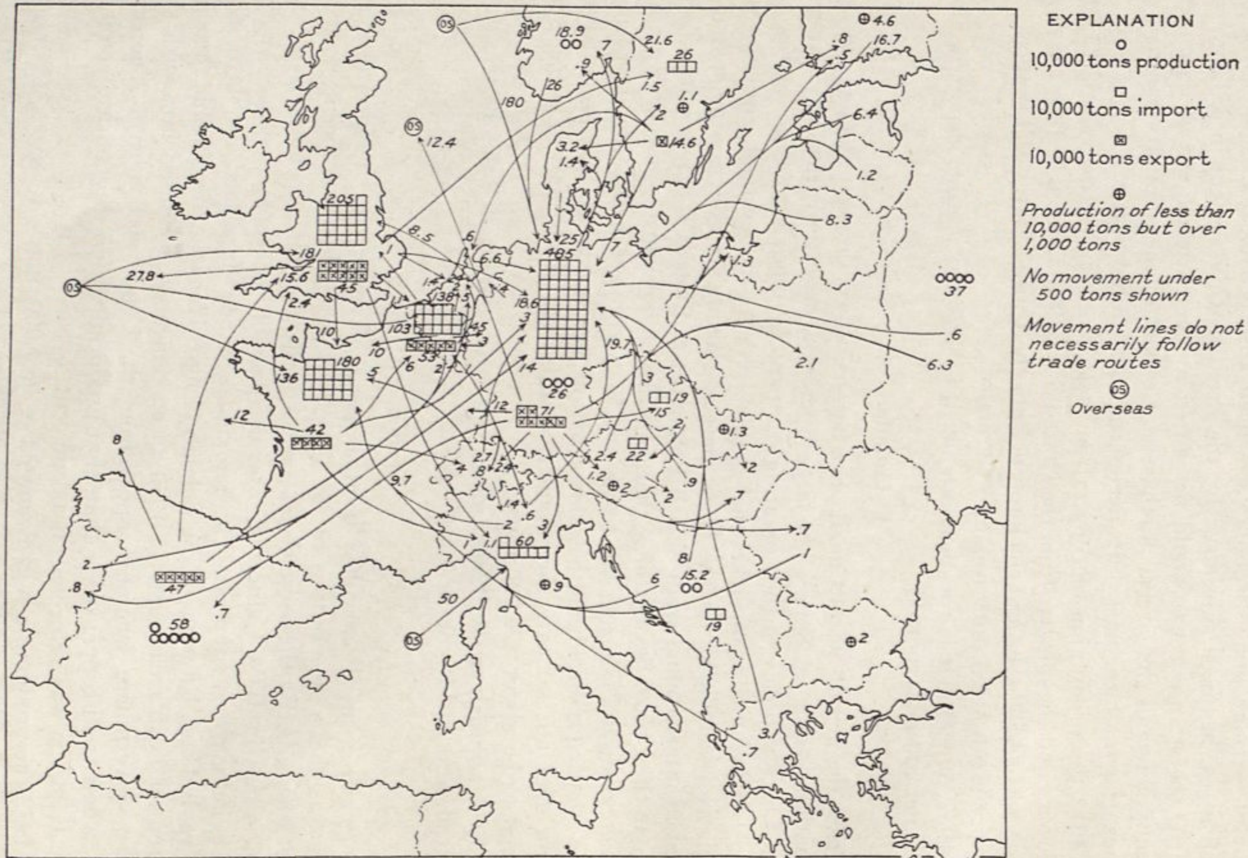
France

For many years France has been a buyer of copper in the international market, as the copper output of the French Republic is not sufficient to take care of its needs. By the commercial control of the Bor mine, in Yugoslavia, and of the mines in Baja California, Mexico, part of the copper needed by the French industry is supplied. The remainder is now furnished by the Union Minière du Haut Katanga of the Belgian Congo. This is made possible through preferential tariff treatment. In 1930 an agreement was entered into with the Belgian Government whereby copper from the Congo was given a 2 percent tariff, whereas all copper other than that produced within the political confines of the Republic was subjected to a 4 percent duty.

In 1932 the production was estimated to be 1,000 metric tons; 92,518 metric tons was imported, and 1,334 metric tons exported.

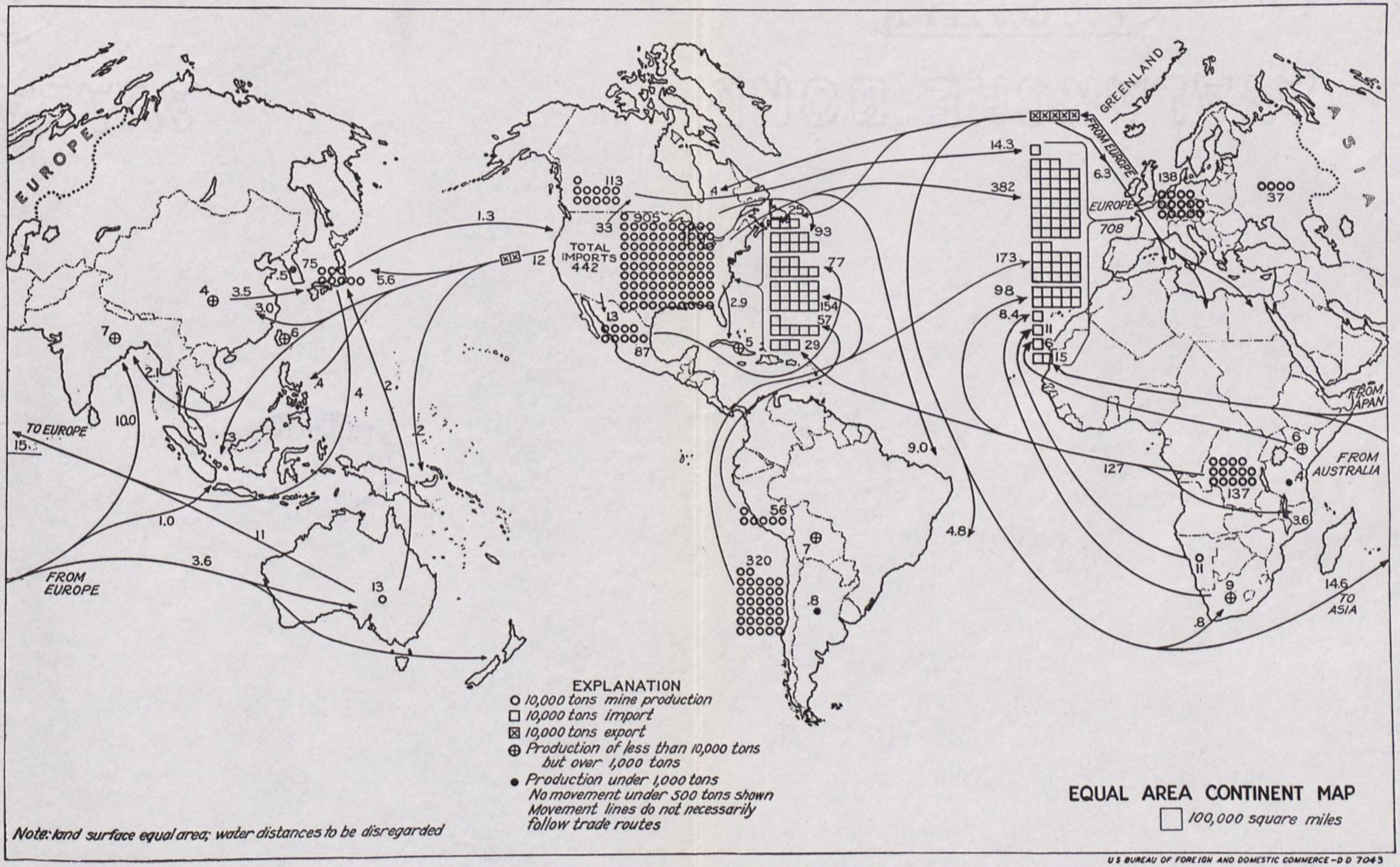
World's production

The following tables give salient figures of the world's production of copper. (See also pl. 1 and fig. 1.)



U. S. Bureau of Foreign and Domestic Commerce

FIGURE 1.—Copper production, imports, and exports of Europe, 1929.



WORLD COPPER PRODUCTION, IMPORTS, AND EXPORTS, 1929

TABLE 5.—*World's smelter production of copper, 1927–31, in metric tons*

[Compiled by L. M. Jones, U. S. Bureau of Mines]

Country[a]	1927	1928	1929	1930	1931
North America:					
Canada[b]	31,947	56,619	72,661	101,554	110,588
Mexico	39,248	46,865	58,997	54,025	43,738
United States	[c]843,850	[c]911,444	[c]998,789	[c]729,611	537,175
	915,045	1,014,928	1,130,447	885,190	691,501
South America:					
Chile	226,160	274,900	303,188	208,011	215,696
Peru	46,377	52,292	53,962	47,287	44,395
	272,537	327,192	357,150	255,298	260,091
Europe:					
Austria	3,308	3,424	3,895	4,076	3,235
Belgium	9,810	[d]9,720	[d]8,940	14,640	31,400
Czechoslovakia	743	1,010	1,694	1,521	1,215
Finland	354	375	235	....	....
France	1,896	1,142	1,010	1,207	[e]1,100
Germany[f]	50,600	48,500	53,600	59,200	55,500
Great Britain[g]	22,600	21,400	22,000	18,000	16,000
Italy	450	900	539	262	721
Norway	13	788	2,400	5,149	4,352
Rumania[i]	215	104	143	169	(h)
Russia[j]	13,597	18,996	[e]25,000	[e]26,000	29,000
Spain	28,689	27,758	28,455	22,996	25,734
Sweden[k]	5,406	3,396	4,748	5,523	2,854
Yugoslavia	12,863	15,086	20,675	24,463	24,351
	150,544	152,599	173,334	183,206	195,362
Asia:					
China[l]	1,052	4,395	3,469	1,203	157
Chosen	1,004	607	547	589	698
India, British	....	....	1,661	3,022	4,134
Japan	66,571	68,233	75,469	79,033	75,848
	68,627	73,235	81,146	83,447	80,837
Africa:					
Belgian Congo	89,156	[m]111,510	[m]135,539	[m]136,404	[b]120,000
Rhodesia:					
Northern	3,343	6,026	5,553	6,370	9,070
Southern	....	110	362	[n]1,334	538
Union of South Africa	9,324	8,849	9,309	[m]7,488	10,225
	101,823	126,495	150,763	151,596	139,833
Oceania: Australia	9,718	12,048	11,049	15,139	13,144
Grand total	1,518,000	1,706,000	1,904,000	1,574,000	1,381,000

[a] In addition to the countries listed, copper is smelted in Asiatic Turkey, but data of output are not available.

[b] Copper content of blister produced.

[c] Smelter output from domestic and foreign material, exclusive of scrap. The production from domestic material only, exclusive of scrap, was as follows: 1927, 763,864 tons; 1928, 828,210 tons; 1929, 908,479 tons; 1930, 632,481 tons; 1931, 472,968 tons.

[d] Figures represent blister copper only. In addition to blister copper, Belgium reports a large output of refined copper which is not included above, as it is believed to be produced principally from crude copper from the Belgian Congo and would therefore duplicate output reported under that country.

[e] Approximate production.

[f] Exclusive of material from scrap (Metallgesellschaft, Stat. Zusammenstellung).

[g] Approximate production (Imp. Inst., London).

[h] Less than 1 ton.

[i] Smelter output from domestic ores.

[j] Year ended Sept. 30.

[k] Exclusive of material from scrap.

[l] Exports of ingots and slabs.

[m] In addition to the crude copper smelted in the Belgian Congo, the following quantities were smelted in Belgium from matte and alloys produced in the Belgian Congo: 1928, 946 tons; 1929, 1,453 tons; 1930, 2,545 tons.

[n] Shipments.

TABLE 6.—*Copper production of leading companies, 1927–31, in short tons*

[From Yearbook of the American Bureau of Metal Statistics]

United States

Company	1927	1928	1929	1930	1931
Anaconda (own mines)	101,955	116,873	140,969	92,662	85,622
Arizona Commercial	2,753	2,333	1,900	1,822	....
Bingham Mines	613	728	[a]245	....	....
Butte & Superior	2,016	933	633	186	....
Calumet & Arizona	24,082	25,866	63,570	43,690	(b)
Calumet & Hecla and subsidiaries	60,077	65,862	67,347	58,199	40,050
Consolidated Coppermines	9,446	10,776	11,366	16,306	7,538
Copper Range	11,337	12,127	12,099	11,900	8,861
East Butte	2,922	4,269	3,492	(c)	....
Engels	6,061	5,569	5,500	2,036	....
Inspiration	44,229	44,062	53,654	32,931	30,684
Iron Cap	790	....	[d]2,209	[d]3,462	[d]1,224
Kennecott Copper Corporation	17,372	14,000	14,091	11,495	6,785
Magma	14,251	18,229	19,128	15,942	14,420
Mason Valley	6,846	8,667	1,804	....	....
Miami	26,519	24,130	29,421	33,562	25,286
Mohawk	11,062	10,622	10,022	6,583	6,550
Mother Lode Coalition	10,294	6,709	6,121	4,823	4,557
New Cornelia	36,466	38,998	(e)	(e)	(b)
Nevada Consolidated	[f]109,342	[f]134,231	[f]133,137	[f]70,990	[f]65,478
North Butte	....	....	1,763	2,770	501
Phelps Dodge (U.S. mines)	74,679	81,861	88,590	56,479	[b]90,567
Ohio Copper	2,413	1,987	1,108	1,024	330
Old Dominion	10,816	8,859	9,472	8,798	5,674
Quincy	4,859	610	2,230	5,470	3,733
Seneca	1,441	....	1,499	2,429	....
Shattuck Denn	2,073	2,468	5,366	4,167	....
United Verde	49,745	59,056	71,145	35,360	9,946
United Verde Extension	20,651	22,600	32,056	22,784	12,295
Utah Apex	3,532	2,334	2,301	1,483	....
Utah Copper	116,501	136,912	148,313	80,569	71,347
Utah Delaware	1,937	1,500	2,731	2,144	640
Walker	4,682	5,178	7,516	7,888	6,425

[a] January–July only.
[b] In 1931 production of New Cornelia and Calumet & Arizona included with Phelps Dodge.
[c] Not reported.
[d] Output of Christmas Copper Co., a subsidiary of Iron Cap.
[e] Included with Calumet & Arizona.
[f] Includes Ray Consolidated and Chino.

Canada

Company	1927	1928	1929	1930	1931
Granby Consolidated	27,706	28,760	30,427	23,416	18,256
Consolidated Mining & Smelting	9,262	8,902	4,173	7,064	607
Britannia (Howe Sound)	17,475	21,101	21,516	22,633	[a]14,309
Noranda[b]	276	16,532	25,612	37,755	31,430
Hudson Bay	....	....	....	1,186	15,534
Sherritt-Gordon	....	....	....	....	7,359

[a] Sales. [b] Includes custom ore.

Mexico

Company	1927	1928	1929	1930	1931
Boleo	11,547	12,755	12,799	13,889	12,705
Cananea	14,369	18,210	29,413	21,212	20,936
Mazapil	5,488	6,456	6,239	4,378	....
Mexican Corporation (Teziutlan unit)[a]	1,441	1,287	1,691	1,719	1,781
Phelps Dodge (Moctezuma)	18,000	20,631	21,035	14,352	13,497

[a] Fiscal year ended June 30.

TABLE 6.—*Copper production of leading companies, 1927–31, in short tons*—Continued.

Other foreign countries

Company	1927	1928	1929	1930	1931
Andes	27,188	52,029	81,332	47,023	41,855
Bor	14,069	16,629	22,790	26,966	26,842
Braden	101,484	109,136	88,163	80,993	103,770
Bwana M'Kubwa	5,434	5,970	6,806	7,226	546
Cerro de Pasco	45,223	49,032	49,993	43,000	42,000
Chile	109,800	132,932	149,788	89,596	85,814
Furukaws	17,911	17,865	17,886	18,536	18,596
Katanga	98,277	123,960	151,006	153,163	132,300
Naltagua	5,620	5,940	6,802	6,107	6,558
Namaqua	2,882	2,800	2,466	1,300	1,300
Mansfeld (from own ores)	25,395	23,396	25,235	23,265	27,619
Mount Lyell	6,566	7,257	10,763	11,126	11,061
Mount Morgan	2,225	....	....	....	....
Poderosa [a]	2,124	3,242	2,905	2,711	636
Roan Antelope	....	....	....	....	20,570
Sumitomo	13,746	17,285	20,792	18,895	18,145

[a] Estimated content of ore shipped.

Refiners [a]

Company	1927	1928	1929	1930	1931
American Metal Co., Ltd.	194,424	221,148	245,856	235,666	168,684
American Smelting & Refining Co.	536,830	563,713	619,398	440,784	271,825

[a] The totals for these concerns are to a large extent duplications of the reports of other producers.

TABLE 7.—*Principal copper producers and the disposition of their copper*

[From Yearbook of the American Bureau of Metal Statistics]

United States

Company	Where smelted	Where refined	Sold by
American Smelting & Refining Co.	Own plants.	Own refineries.	American Smelting & Refining Co.
Anaconda Copper Mining Co.	Anaconda Copper Mining Co., Anaconda, Montana.	Anaconda Copper Mining Co., Great Falls, Montana.	United Metals Selling Co.
Calumet & Hecla Consolidated Copper Co.	Calumet & Hecla Mining Co., Hubbell, Michigan.	Calumet & Hecla Mining Co., Hubbell, Michigan.	Calumet & Hecla Consolidated Copper Co.
Champion Copper Co.	Michigan Smelting Co., Houghton, Michigan.	Michigan Smelting Co., Houghton, Michigan.	Copper Range Co.
Consolidated Coppermines Corporation	Nevada Consolidated Copper Co., McGill, Nevada.	American Smelting & Refining Co., Baltimore, Maryland.	Consolidated Coppermines Corporation.
Copper Range Co.	Michigan Smelting Co.	Michigan Smelting Co.	Copper Range Co.
Ducktown Chemical & Iron Co.	Ducktown Sulphur, Copper & Iron Co., Isabella, Tennessee.	Nichols Copper Co., Laurel Hill, New York.	Nichols Copper Co.
Inspiration Consolidated Copper Co.	Part to International Smelting Co., Miami, Arizona.	Own plant, Inspiration, Arizona; Raritan Copper Works, Perth Amboy, New Jersey.	Metals Sales Corporation.
Isle Royale Copper Co.	Michigan Smelting Co.	Michigan Smelting Co.	Calumet & Hecla Consolidated Copper Co.
Kennecott Copper Corporation	American Smelting & Refining Co., Tacoma, Washington.	American Smelting & Refining Co., Tacoma, Washington.	Guggenheim Bros.
Magma Copper Co.	Magma, Superior, Arizona.	Nichols Copper Co.	International Minerals & Metals Corporation.
Miami Copper Co.	International Smelting Co., Miami, Arizona.	Raritan Copper Works.	Adolph Lewisohn & Sons.
Mohawk Mining Co.	Michigan Smelting Co.	Michigan Smelting Co.	Mohawk Mining Co.
Mother Lode Coalition Mines Co.	American Smelting & Refining Co., Tacoma, Washington.	American Smelting & Refining Co., Tacoma, Washington.	Guggenheim Bros.
Nevada Consolidated Copper Co.	(a)	American Smelting & Refining Co., Baltimore, Maryland.	Guggenheim Bros.
North Butte Mining Co.	Anaconda Copper Mining Co., Anaconda, Montana.	Anaconda Copper Mining Co., Great Falls, Montana.	United Metals Selling Co.
Ohio Copper Co.	American Smelting & Refining Co., Garfield, Utah.	American Smelting & Refining Co., Baltimore, Maryland.	American Smelting & Refining Co.
Old Dominion Co.	International Smelting Co., Miami, Arizona.	Raritan Copper Works.	Phelps Dodge Corporation.

Phelps Dodge Corporation	Own plants, Douglas and Clifton, Arizona.	Nichols Copper Co.	Phelps Dodge Corporation.
Quincy Mining Co.	Quincy Smelting Works, Hancock, Michigan.	Quincy Smelting Works, Hancock, Michigan.	Quincy Mining Co.
Tennessee Copper Co.	Tennessee Copper Co., Copperhill, Tennessee.	Nichols Copper Co.	Adolph Lewisohn & Sons.
United Verde Copper Co.	United Verde Copper Co., Clarkdale, Arizona.	American Metal Co., Carteret, New Jersey.	United Verde Copper Co.
United Verde Extension Mining Co.	United Verde Extension Mining Co., Clemenceau, Arizona.[b]	Nichols Copper Co.	Nichols Copper Co.
Utah Delaware Mining Co.	International Smelting Co., Tooele, Utah.	Anaconda Copper Mining Co., Great Falls, Montana.	United Metals Selling Co.
Utah Copper Co.	American Smelting & Refining Co., Garfield, Utah.	American Smelting & Refining Co., Baltimore, Maryland.	Guggenheim Bros.
Walker Mining Co.	International Smelting Co., Tooele, Utah.	Anaconda Copper Mining Co., Great Falls, Montana.	United Metals Selling Co.

[a] Nevada Consolidated ores are treated at McGill, Nevada; Chino ores at El Paso, Texas; and Ray Consolidated ores at Hayden, Arizona.

[b] Also ships silica ore to Hayden, Arizona.

Canada

Amulet Mines, Ltd.	Noranda Mines, Ltd.	Canadian Copper Refiners, Ltd.	British Metal Corporation.
Consolidated Copper & Sulphur Co.	Nichols Copper Co.	Nichols Copper Co.	Nichols Copper Co.
Granby Consolidated Mining, Smelting & Power Co.	Granby Consolidated, Anyox, British Columbia.	Nichols Copper Co.	Nichols Copper Co.
Hudson Bay Mining & Smelting Co., Ltd.	Own plant, Flin Flon, Manitoba.	Canadian Copper Refiners, Ltd.	British Metal Corporation.
Noranda Mines, Ltd.	Own plants, Rouyn, Quebec.	Canadian Copper Refiners, Ltd.	British Metal Corporation.
Britannia Mining & Smelting Co.	American Smelting & Refining Co., Tacoma, Washington.	American Smelting & Refining Co., Tacoma, Washington.	American Smelting & Refining Co.
International Nickel Co. of Canada, Ltd.	Own plants, Copper Cliff and Coniston, Ontario.	Ontario Refining Co., Ltd.	American Metal Co. of Canada, Ltd.
Sherritt-Gordon Mines, Ltd.	Hudson Bay Mining & Smelting Co.	Ontario Refining Co., Ltd.	Consolidated Mining & Smelting Co.
Waite-Ackerman-Montgomery Mines, Ltd.	Noranda Mines, Ltd.	Canadian Copper Refiners, Ltd.	British Metal Corporation.

TABLE 7.—*Principal copper producers and the disposition of their copper*—Continued.

Company	Where smelted	Where refined	Sold by
Mexico			
Cie. du Boléo	Boleo, Santa Rosalia, Baja California.	American Smelting & Refining Co., Tacoma, Washington.	American Smelting & Refining Co.
Cananea Consolidated Copper Co.	Cananea Consolidated, Cananea, Sonora.	Raritan Copper Works.	Metals Sales Corporation.
Moctezuma Copper Co.	Phelps Dodge, Copper Queen branch, Douglas, Arizona.	Nichols Copper Co.	Phelps Dodge Corporation.
Other foreign countries			
Andes Copper Mining Co.	Own plant, Potrerillos, Chile.	Raritan Copper Works and own plant in Chile.	United Metals Selling Co.
Braden Copper Co.	Own plant, Caletones, Chile.	Own plant in Chile.	Guggenheim Bros.
Cerro de Pasco Copper Corporation	Own plant, Oroya, Peru.	American Metal Co., Carteret, New Jersey.	American Metal Co.
Chile Exploration Co.	....	Own plant, Chuquicamata.	Metals Sales Corporation.
Corocoro United Copper Mines	American Smelting & Refining Co., Tacoma, Washington (in part).	American Smelting & Refining Co., Tacoma, Washington (in part).	Minerais & Métaux, Paris, France.
Cía. de Minas de Gatico	Own plant, Gatico, Chile.	Nichols Copper Co.	British Metal Corporation.
Union Minière du Haut Katanga	Own plant, Belgian Congo.	Norddeutsche Affinerie (Hamburg); own plants in Africa and Belgium.	Société générale des minerais, Brussels, Belgium.
Matahambre Mines	American Metal Co., Carteret, New Jersey.	American Metal Co.	American Metal Co.
Roan Antelope Copper Mines	Own plant, Rhodesia.	American Metal Co.	American Metal Co.
Otavi Mines & Ry. Co.	Own plant, Southwest Africa; Société générale métallurgique de Hoboken, Belgium, and Norddeutsche Affinerie.	Various.	Société générale des minerais, Brussels, Belgium, and Metallgesellschaft.
Rhokana Corporation	Own plant, Rhodesia.	American Metal Co.	American Metal Co.

Summary

Since 1930, through national enactments and otherwise, the international trade routes have been materially changed. Prior to 1930, with no tariff barriers in the major countries—for example, the United States, Germany, England, France, and Italy—the European prices could not vary greatly from the price in the United States. If large offers were made in the United States market at a price below the current world price, this was necessarily reflected in all foreign markets. If a European producer lowered the price, however, it did not affect the world price, as the world demand could not be satisfied from sources other than those under the commercial control of nationals of the United States. These conditions in the world market, which culminated in 1928, resulted in bringing into production sources of copper throughout the world which had hitherto been latent. This production rapidly increased, so that by the middle of 1930 the industrial countries were able to obtain their copper requirements from sources other than those controlled by nationals of the United States. This increased production, combined with decreased demand, as well as the various tariff enactments made throughout the world, made it absolutely necessary to shift the international flow of copper. Plate 1 shows the flow of copper in the world markets, as indicated by production, imports, and exports in 1929.

The situation at the end of 1932, broadly viewed, shows that the South American producers controlled by nationals of the United States are now debarred from sharing in the United States market and must seek markets elsewhere. The rapid expansion of production within the British Empire has already made it evident that there is an exportable surplus over and above the Empire's requirements. The Canadian output is in part controlled by the consumption of nickel; also most of the Canadian copper ores contain gold; and in order to meet their financial obligations, the operators must maintain production. Similarly, the Rhodesian operators are forced by their heavy capital commitments to continue in production. The international situation is further complicated by the fact that a market must be found for the output of the Union Minière du Haut Katanga, of the Belgian Congo. Some of this Katanga copper finds an exclusive market in France, where preference is accorded to Belgian copper, but the larger part of the output must find markets elsewhere.

The international situation at the end of 1932, then, may be summarized as follows:

The United States is self-sufficient from the product of its domestic mines, and the copper produced by foreign mines under the control of its nationals enters the international market; the British Empire is self-sufficient and with an exportable surplus; the Belgian Congo must seek, for much of its production, markets other than France; France finds it markets satisfied by imports from Belgium and from mines controlled by its nationals; the Union of Soviet Socialist Republics is rapidly becoming self-sufficient; of the larger consuming countries, only Germany and Italy are able to absorb a part of the excess copper. The conditions are further complicated by the fact that the exchange situation in Germany makes it difficult for the exporter to transact business there.

Figure 1 shows the movements of copper in European markets in 1929.

Japan has not been mentioned in this summary, for within the confines of the Japanese Empire sufficient copper can be produced to meet its own requirements. The entrance of Japan into the international market, either as an exporter or an importer, is a matter of policy and not a matter of necessity so far as resources are concerned.

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Economic history of the copper industry

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Copper is an indestructible metal. Practically all that has been mined from the earth's crust is still in use or might be reclaimed for re-use.

The world's recorded production since 1801 has been 48,000,000 short tons, of which five-eighths was produced in the last 22 years and three-eighths in the last decade. Of this recorded production, the United States has contributed about half, and 95 percent of that has come from 15 districts in 9 States. Of the foreign fields, South America has four areas, three in Chile and one in Peru. Canada has six, Mexico three, Africa four, and the remainder of the world about a dozen. It would be safe to say that all the copper so far mined has come from beneath an aggregate area of the earth's surface of less than 100 square miles. No important producing district in the world has yet been exhausted.

This high degree of concentration has led to a similar and even greater concentration of ownership. As we shall see later, 24 corporations have supplied three-fourths of the world's output in the last 7 years, and 14 with their subsidiaries have supplied 64 percent.

The estimated known reserves of metal in the ground are about 100,000,000 tons, more than twice the amount the world has consumed in the last 132 years. This total cannot be regarded as a possible or probable limit but merely records the current estimate of known reserves of metal contained in material from which it can be profitably extracted by present methods at normal prices. It is capable of practically indefinite expansion by the factors of technologic advance and higher price, as well as the discovery of new deposits. Of these reserves 85 percent is owned by eight corporations. Nearly 40 percent is owned by the three largest copper groups in the United States, about evenly divided between their properties in the United States, Mexico, and South America. One corporation in Canada and three in Africa own another 40 percent. The controlling interest in these African units rests with British Empire capital, but probably 40 percent is at present in American hands. About a 50 percent interest in the Canadian corporation is also American-owned. The remaining unit in Africa is controlled by the Belgian Government, with about 35 percent minority interest in British hands.

This extraordinary concentration of ownership, of both current and future supplies, has not prevented the industry from suffering wide fluctuations in earning power and employment. This is strikingly illustrated by the fact that the securities of a group of American-owned companies in North and South America which produced 60 percent of the world's total output during the 12-year cycle from the lows of 1921 to the lows of 1932 were valued in the open market in 1921 at $700,000,000, at the highs of 1929 at $3,350,000,000, and at the lows of 1932 at $222,000,000. (See table 3.) The monthly average New York price for electrolytic copper rose from 11.50 cents a pound in 1921 to a peak of 23.87½ cents a pound in March, 1929, and declined to an all-time low of

4.87½ cents in 1932. The annual production of these companies was 260,000 short tons in 1921, 1,250,000 tons in 1928, and 440,000 tons in 1932. (See table 1.)

The creditors and owners of these companies received in interest and dividends some $19,200,000 in 1921, $150,400,000 in 1929, $8,400,000 in 1932, and $5,500,000 in 1933. The annual average for the 12-year period was $65,000,000. During the last 30 years the average cost of establishing copper production in North and South America—that is, to acquire properties, develop and equip mines, mills, smelters, and refineries, produce electrolytic or fire-refined copper, and provide adequate working capital—has been about 30 cents per pound of annual capacity. The aggregate cash investment of the particular group we have been considering has been about $750,000,000. An annual average return of $65,000,000 over the 12-year cycle from 1921 to 1932 does not suggest that the industry has been the victim of cut-throat competition. On the contrary, more real price competition and less attempted price stabilization would undoubtedly have averted much of the present overdevelopment and profitless production.

Employment showed similar wide fluctuations. Copper mines, mills, and smelting plants in the United States employed about 45,000 men in 1929, as compared with 13,000 in 1932 and about 12,000 in the first quarter of 1933. The increase in employment from 1919 to 1929 was less than 2 percent, while production increased 70.0 percent. This affords some measure of the technologic advances in the industry, which have been a major factor in increasing the known reserves of metal in the ground by making available for profitable extraction lower-grade material.

Such changes in the condition of the employees and owners of the copper industry point directly to the pursuit of policies tending to accentuate the cyclic character of the industry rather than to mitigate it. This character arises from the fact that some 70 percent of the industry's product goes into producer's goods and the balance only into consumer's goods, though all of the latter are of a more or less permanent character. The electrical industries take 50 to 55 percent of the output. The building trades, automotive industry, and household equipment absorb another 18 to 21 percent; manufactures for export about 7 percent. Fully 70 percent of the consumption, therefore, rises and falls with the rise and fall of activity in expanding facilities for production. Except in the electrical fields, copper must meet severe competition on the basis of price and service from other metals and a rapidly growing list of alloys. Even in the field of electrical transmission it encounters strong competition from aluminum.

Because of the great concentration of ownership, the apparent security of the demand for copper in the electrical field, and the wide fluctuations in demand for producer's goods, the industry has been especially vulnerable to monopolistic and speculative practices. Repeatedly, policies appear to have been based on the theory that the world must have copper regardless of price and, therefore, if the supply could be controlled, it would be possible to establish almost any price—and a corresponding profit. To name the outstanding attempts at control in the past, we have the French, or Secretan Syndicate of 1887, the Amalgamated Pool of 1889 and that of 1907, the Copper Export Association pool of

1920, and the Copper Exporters, Inc., of 1928–30. These pools, particularly the latest, were temporarily successful in raising prices and profits to high levels. Inevitably, however, the structure crumbled away under the weight of unsold metal and the ability of the consumer to cease purchasing material for enlarging his facilities when prices become too high. Usually these attempts have synchronized with prophecies of pending world shortage of copper. They greatly stimulated the search for new sources of supply and cheaper methods of extraction and rendered easy the task of obtaining the capital needed to exploit these discoveries. The causal relations between these pools and the speed of development of the various important additions to known supplies in the last 40 years can readily be traced—Morenci, Bisbee, Globe, and Jerome in Arizona in the nineties; "porphyries" in Utah, Arizona, Nevada, and New Mexico in the first decade of this century; the South American "porphyries" and the Belgian Congo in the second decade; and the Rhodesian and Canadian deposits in the third. Partly as a result of these stimuli the United States is now equipped to produce 1,200,000 tons of refined copper a year, and the rest of the world 1,500,000 tons. The actual consumption in 1932 was 336,000 tons in the domestic market and 741,000 tons in the foreign market. With very little additional capital the aggregate capacity of the world could be increased to 3,000,000 tons, 50 percent more than the peak consumption of 1929 and almost three times that of 1932. But it is likely to be a long time before there is a resumption of public investment in the development of new sources of copper supply. Barring some possible but unanticipated invention that may expand or contract the uses of copper, this reluctance on the part of capital will presently restore the balance of supply and demand and a normal margin of profit to the industry.

The collapse of prices after the World War stressed the search for cheaper methods, and A. B. Parsons has brought out very clearly the success of this campaign in a book published recently by the American Institute of Mining and Metallurgical Engineers, entitled "The porphyry coppers." Parsons cites the facts that the Utah Copper Co. produced copper for about 6½ cents a pound in 1928 from ores yielding only 17 pounds to the ton, and that if the company had been compelled to use the equipment and methods available to it in 1916, while carrying the increased wages, costs of supplies, and taxes of 1928, the copper would have cost 12¼ cents instead of 6½ cents. From 1921 the industry slowly recovered from the postwar collapse, and by 1927 profits had steadily increased to a point that might be regarded as normal, at a much lower level of cost and price.

Despite the discovery and active development of probably the greatest known copper deposit in the world, that of Northern Rhodesia, in central Africa, the addition of the Andes Copper Co. to the list of large producers in South America, and the exploitation of the Frood copper-nickel deposit of the International Nickel Co. of Canada and the copper deposits of the Noranda and the Hudson Bay companies, the price of electrolytic copper rose rapidly from 13.87½ cents a pound in the second half of 1928 to 23.87½ cents a pound early in March, 1929, in spite of the fact that on December 1, 1928, the stocks of unsold metal had shown the first increase in 9 months. In March the price slipped back rapidly to 18 cents, where it was resolutely held, in spite of rapidly growing stocks, until April, 1930.

It is important to realize that copper consumption had started to decline even before the peak of prices was reached, and that the price had been held to 18 cents for 15 months after the collapse of the security market in October, 1929. Production was cut, only to have consumption decrease still faster. Finally, in April, 1930, under the pressure of rising cost and inventory, the structure cracked and crumbled. The world did not have to have copper at 18 cents, or 14, or 12, or 10, or 8, or even at 6 cents, when the consumer could see that there was a greater quantity for sale than could be absorbed and that this supply was being constantly increased. In other words, there was far more copper available than people could buy.

The three largest units of the domestic industry of the United States are partly or completely integrated vertically from mine to consumer and in addition are heavily interested in foreign production. Two other large units are partly or completely integrated through smelting, refining, and fabricating. In addition, secondary metal from scrap, both that arising from the fabrication of virgin copper and that from the demolition of old installations, is handled by several plants, including those already referred to. One of these units is also largely interested in foreign production.

The financial history of the copper industry strongly suggests that up to date there has been one element of marked stability—namely, that portion of the selling price that has been available for distribution to creditors and owners as interest and dividends. In spite of wide fluctuations over brief intervals, the tendency has been for this figure to return to a normal, measured over any material period. Perhaps this denotes the economic profit which the industry has needed in the past to maintain it in sound condition, able and ready to attract the necessary capital to increase its capacity to supply growing demand. (See tables 1–4.)

As can be seen, all attempts to exact profits in excess of this normal have at the best succeeded only temporarily, to be followed by prolonged periods of depression and slow recovery, which brought the average back to normal. If the future normal could be expected to accord with that of the past, it would be simple to conclude that the peaks and troughs of employment and earnings could be greatly mitigated through a control based on maintaining the average profit of the past. At least the fluctuations might be reduced to those inherent in any industry whose product is primarily producer's goods, purchased freely only in times of expansion of productive facilities.

The temporary successes of these attempts to maintain abnormal profits, however, have so stimulated the search for and development of new sources of supply that the world now has greater known reserves of metal in the ground and greater existing capacity to produce in proportion to current needs than ever before in its history. In addition, the constantly growing volume of metal above ground available for re-use, as present structures and machines become obsolete, increases the ease with which new demand can be met.

The development of economic nationalism, whether arising from the natural instinct to survive, or the instinct of groups to prosper beyond their fellows, or the fear of a lack of the necessities for war in case of attack, tends to expand available supplies and facilities for processing. The imposition of tariffs by various countries bears witness to this fact.

The constant development and extension of the use of alloys possessing special properties for special services is steadily increasing competition. The obvious approach of saturation in the domestic market for coal and for iron ores as a raw material of the steel industry for similar reasons points to a like fate for the nonferrous metals.

Under the probable conditions of the future, continuation of those policies of the past, in which price maintenance has been the keynote, cannot fail to bring greater troughs of unemployment and greater loss of earnings and capital than have yet been experienced. The path of prudence calls, therefore, not for any attempt to obtain the average profit margin of the past but to work frankly for a substantially lower margin by establishing controls that will restrict output whenever that margin tends to decrease or disappear and permit free increase of output whenever it returns. A free price will work in harmony with and reinforce such control rather than in opposition to it. To reestablish a free market at a profitable level, the first essential is the reduction of stocks of unsold metal. To accomplish this as rapidly as possible, the price level must be prevented from rising high enough to interfere with this reduction by inducing increased output.

The following tables give numerous details concerning the operations of the leading companies.

TABLE 1.—*Average cost of producing copper, 1926–32*

Company	Production (pounds)	Calculated earnings		Selling price per pound (cents)	Cost per pound (cents)
		Total	Per pound (cents)		
Anaconda (Butte)	1,401,802,000	$43,530,996	3.34	13.32	9.98
Andes	491,367,270	20,225,592	4.45	14.50	10.05
Chile	1,424,154,920	71,358,461	5.01	13.14	8.13
Greene Cananea	276,140,336	5,687,117	2.06	12.41	10.35
Inspiration	501,043,445	8,744,881	1.74	13.04	11.30
Calumet & Hecla	623,907,470	18,799,393	3.01	13.63	10.62
Cerro de Pasco	596,110,000	19,231,133	3.23	12.96	9.73
Copper Range	132,928,914	2,050,051	1.54	13.51	11.97
Kennecott (Utah, Braden, Alaska)	2,821,725,525	158,088,942	5.49	13.35	7.86
Nevada Consolidated	1,317,461,967	36,040,996	2.74	12.92	10.18
Mother Lode	95,669,460	4,679,044	4.89	13.46	8.57
Phelps Dodge	1,877,028,141	44,617,616	2.38	13.01	10.63
Granby	316,211,461	12,915,634	4.08	13.77	9.69
Magma	222,277,090	8,528,337	3.84	12.73	8.89
Miami	348,939,166	5,478,536	1.57	13.51	11.94
Mohawk	88,533,816	5,047,541	5.70	14.10	8.40
Old Dominion	107,954,571	−1,106,107	−1.02	13.30	14.32
United Verde Extension	282,064,058	13,975,177	4.96	13.48	8.52
	12,925,320,000	477,893,340	3.69	13.27	9.58
Noranda	286,222,934	17,630,254	6.16	11.38	5.22
Hudson Bay	75,598,000	2,961,631	3.92	6.84	2.92
Katanga	1,501,192,980	28,957,775	1.93	13.20	11.27
Grand total	14,788,334,000	527,443,000	3.56	13.19	9.63

NOTE.—The subtotal gives the production controlled by nationals of the United States. The grand total represents 64.14 percent of the world's production for the 7 years.

In the foregoing table earnings have been calculated on the basis of aggregate interest and dividends paid out, plus or minus any increase or decrease in net current assets, plus any cash investments from earnings in increased facilities to produce or in the securities of other copper-producing companies, less any interest and dividends received from other copper-producing companies and any cash received from the sale of new capital issues. Profits from the production of other metals, as gold, silver, lead, and zinc, have all been credited to the cost of copper. Similarly profits from custom smelting, refining, and manufacturing enjoyed by certain of the companies have also been credited to the cost of copper. Where the investment in such facilities has been wise, it has improved the competing power of the unit in the industry; where unwise, it has proved a handicap. The results are not different in kind from those inherent in higher copper or higher precious-metal contents of their ores than those of their competitors.

Table 2 gives the same data for the operations in the United States of the companies listed in table 1.

TABLE 2.—*Average cost of producing copper in the United States, 1926–32*

Company	Production (pounds)	Calculated earnings		Selling price per pound (cents)	Cost per pound (cents)
		Total	Per pound (cents)		
Anaconda (Butte)	1,401,802,000	$43,530,996	3.34	13.32	9.98
Inspiration	501,043,445	8,744,881	1.74	13.04	11.30
Kennecott (Alaska)[a]	....	....	....	....	9.50
Utah	1,396,826,000	75,398,000	5.40	13.35	7.95
Nevada Consolidated	1,317,461,967	36,040,996	2.74	12.92	10.18
Phelps Dodge	1,877,028,141	44,617,616	2.38	13.01	10.63
Calumet & Hecla	596,110,000	19,231,133	3.23	12.96	9.73
United Verde Extension	282,064,058	13,975,177	4.96	13.48	8.52
Magma	222,277,090	8,528,337	3.84	12.73	8.89
Miami Copper	348,939,166	5,478,536	1.57	13.51	11.94
Copper Range	132,928,914	2,050,051	1.54	13.51	11.97
United Verde[a]	....	....	....	....	9.50–9.75
	8,076,480,781	257,595,723	3.19	13.14	9.95
Operations outside of the United States, including foreign companies	6,712,000,000	265,286,000	3.95	13.42	9.47

[a] Details not available; figure given is probable average cost.

NOTE.—Phelps Dodge figures include those of its Mexican property (Moctezuma Copper), whose costs were probably slightly higher than the average. Anaconda and Phelps Dodge figures include manufacturing profits and some custom smelting and refining profits. Kennecott figures include manufacturing profits.

TABLE 3.—*Market value of securities and yield, 1920–32*

Year	Year-end market value of securities (000,000 omitted)	Yield based on interest and dividend payments (percent)
1920 (lows)	$700	1.74
1921	913	2.10
1922	876	2.64
1923	959	6.43
1924	1,160	4.74
1925	1,142	5.67
1926	1,140	6.58
1927	1,144	7.12
1928	2,439	3.88
1929 (highs)	3,351	4.76
1929	1,803	8.84
1930	754	11.93
1931	334	9.67
1932 (December 29)	222	2.35

NOTE.—Companies included are Anaconda, Andes, Chile, Greene, Inspiration, Calumet & Arizona, Phelps Dodge, Kennecott, Nevada, Mother Lode, Calumet & Hecla, Cerro, United Verde, United Verde Extension, Granby, Miami, Magma, Mohawk, Old Dominion, and Copper Range. The figures for market value have been adjusted for duplications due to ownership of securities by other members of the group. All fixed obligations have been valued at par.

Table 4 gives similar data to tables 1 and 2 for a large section of the United States owned industry in North and South America, including the following companies: Anaconda, Andes, Chile, Greene, Inspiration, Kennecott, Utah, Nevada, Mother Lode, Braden, Phelps Dodge, Calumet & Arizona, Cerro de Pasco, Copper Range, Granby, Magma, Miami, Mohawk, Old Dominion, United Verde, and United Verde Extension. These figures include only interest and dividends paid, adjusted for any duplication of dividends but not adjusted for changes in net current assets, etc., as in tables 1 and 2.

TABLE 4.—*Selling price and interest and dividends paid by certain companies, 1921–32*

Year	Production (pounds) (000 omitted)	Average selling price per pound (cents)	Bond interest and dividends paid		Percent of average selling price paid out in bond interest and dividends
			Total (000 omitted)	Per pound (cents)	
1921	520,100	12.50	$19,200	3.69	29.5
1922	1,064,000	13.38	23,100	2.17	16.2
1923	1,581,000	14.42	61,700	3.90	27.0
1924	1,924,000	13.02	55,000	2.75	19.6
1925	2,030,000	14.04	64,600	3.13	22.6
1926	2,114,000	13.86	75,000	3.55	25.7
1927	2,156,900	12.92	82,500	3.82	29.6
1928	2,496,500	14.57	94,900	3.85	26.4
1929	2,440,800	18.11	159,400	5.93	32.7
1930	1,888,600	12.98	95,600	4.97	38.3
1931	1,702,400	8.116	41,300	2.43	29.9
1932	882,200	5.555	8,400	.95	17.1
	21,100,400	13.52	780,700	3.70	27.3

Table 5 gives similar figures for the Michigan industry for 1861–1910, and table 6 gives similar figures for the same companies as table 4 for 1911–32.

TABLE 5.—*Selling price and interest and dividends paid by Michigan copper industry, 1861–1910*

Period	Production (pounds) (000 omitted)	Average selling price per pound (cents)	Bond interest and dividends paid		Percent of average selling price paid out in bond interest and dividends
			Total (000 omitted)	Per pound (cents)	
1861–65	68,605	33.58	$3,080	4.48	13.4
1866–70	103,448	24.48	1,290	1.24	5.1
1871–75	150,965	25.58	10,910	7.22	28.2
1876–80	211,375	18.70	10,449	4.95	26.5
1881–85	312,208	15.18	11,482	3.68	24.2
1886–90	433,005	13.75	12,615	2.91	21.2
1891–95	593,666	10.75	15,980	2.69	25.0
1896–1900	721,829	13.84	38,403	5.32	38.4
1901–5	957,136	14.30	30,574	3.19	22.3
1906–10	1,121,800	15.77	45,499	4.06	25.7
	4,674,037	15.21	180,302	3.86	25.4

TABLE 6.—*Selling price and interest and dividends paid by United States owned industry in North and South America, 1911–32*

Period	Production (pounds) (000 omitted)	Average selling price per pound (cents)	Bond interest and dividends paid		Percent of average selling price paid out in bond interest and dividends
			Total (000 omitted)	Per pound (cents)	
1911–15	5,420,000	15.37	$202,860	3.74	24.3
1916–20	8,250,000	23.35	520,140	6.30	27.0
1921–25	7,119,100	13.64	223,600	3.14	23.0
1926–30	11,396,700	14.88	507,400	4.47	30.0
	32,185,800	16.86	1,454,000	4.52	26.8
1931	1,702,400	8.116	41,300	2.43	29.9
1932	882,200	5.555	8,400	.95	17.1
	34,770,400	16.14	1,503,700	4.30	26.6
Omitting war period (1916–20)	26,520,400	13.93	982,560	3.70	26.6

Study of these data, particularly those covering the complete price cycle from 1921 lows to 1932 lows in table 2, offers convincing evidence that an average margin of 3.25 cents a pound in real earnings for the United States industry and 3.75 cents for the world industry as a whole is about all that it can be expected to earn and is what is needed to sustain it in a sound condition.

TABLE 7.—*Investment in mine development, plant, and equipment and net working capital of North and South American copper companies, December 31, 1929*

Company	Ore mined, 1929 (tons)	Copper produced, 1929 (pounds)		Investment in mine development, plant, and equipment			
		Actual output	Rated capacity (000,000 omitted)	Total	Per ton of ore mined	Per pound of actual output (cents)	Per pound of rated capacity (cents)
Andes	8,000,000	162,663,775	200	$49,746,353	$6.20	30.6	24.9
Braden[a]	4,223,856	156,758,171	200	38,791,843	9.28	24.7	19.4
Chile	11,000,000	299,575,752	375	59,611,427	5.42	20.0	16.0
Calumet & Arizona	4,428,746	130,486,607	140	18,249,620	4.12	14.0	13.0
Inspiration	5,773,858	107,516,201	120	40,739,288	7.06	37.8	34.0
Miami	5,017,983	58,841,159	75	14,600,000	2.91	24.8	19.5
Nevada	12,888,289	266,274,918	350	58,278,185	4.52	21.9	16.6
Noranda	428,221	51,625,478	65	10,418,203	2.43	24.3	16.0
Phelps Dodge	4,604,716	218,360,613	240	44,469,934	9.66	20.4	18.5
Utah Copper	17,724,100	296,274,918	375	48,500,000	2.74	16.4	12.9
	74,089,000	[b]1,748,378,000	2,140	[c]383,404,900	[c]5.17	[c]21.9	17.9

Company	Net working capital				Total investment		
	Total	Per ton of ore mined	Per pound of actual output (cents)	Per pound of rated capacity (cents)	Per ton of ore mined	Per pound of actual output (cents)	Per pound of rated capacity (cents)
Andes	$1,656,007	$0.20	1.0	0.8	$6.40	31.6	25.7
Braden[a]	[a]13,371,000	3.16	8.5	6.7	12.44	33.2	26.1
Chile	19,280,178	1.75	6.4	5.1	7.17	26.4	21.1
Calumet & Arizona	8,485,891	1.92	6.5	6.1	6.04	20.5	19.1
Inspiration	6,697,505	1.15	6.2	5.6	8.21	45.0	39.6
Miami	6,147,311	1.22	10.4	8.2	4.13	35.2	27.7
Nevada	28,039,692	2.18	10.3	8.0	6.70	32.2	24.6
Noranda	5,204,295	1.22	10.1	8.0	3.65	34.4	24.0
Phelps Dodge	32,241,677	7.00	14.8	13.4	16.66	35.2	31.9
Utah Copper	28,007,559	1.58	9.4	7.5	4.32	25.8	20.4
	[d]149,140,000	1.96	8.5	6.9	[cd]7.13	30.4	24.8

[a] Latest available figures are for 1924, but at that time Braden was borrowing its working capital from Kennecott, and the working capital shown is taken at the average figure per pound of the group.

[b] The average copper recovered per ton treated by the group was 23.67 pounds.

[c] Certain additions should be made to this figure to cover the cost of smelting and converting facilities for Inspiration, Miami, Utah, and two-thirds of Nevada. This would bring the total to about $400,000,000, or $5.39 per ton and 22.9 cents per pound of actual output in 1929. The total product would then be ready for market as blister copper except part of that from Andes and Calumet & Arizona and all of that from Chile, which would be electrolytic, and Braden, which would be "best select casting copper." To provide refining facilities for the blister copper would require an additional investment of about $30,000,000 in plant, bringing the total to $430,000,000, or $5.79 per ton and 24.6 cents per pound.

[d] The history of the industry clearly shows that to be in comfortable position and avoid undesirable borrowing, net working capital should equal 1 year's cost before depreciation and depletion. In 1929 this cost was about 8.5 cents per pound for the group given in the table.

Table 7 shows the actual cash investment in mine development, plant, equipment, and working capital which the industry has made. An annual return of 3.25 cents a pound on an investment of 30 cents a pound of annual capacity, to return capital with interest and profit, is a fair yield. As a matter of fact, at the present moment (July, 1933) the industry is valued on the securities market at about 30 cents a pound of annual capacity. Obviously it is not earning any such return under existing conditions, but the investing and speculating public apparently believe that, as in the past, it will return to that level.

TABLE 8.—*Employment by principal United States copper producers, 1927, 1929, and 1931, and by largest producers, 1932*

Year	Mines		Mills and smelters		Total	
	Average number of men employed	Man-shifts worked	Average number of men employed	Man-shifts worked	Average number of men employed	Man-shifts worked
1927	22,384	7,436,021	11,173	3,967,820	33,557	11,403,841
1929	31,278	10,287,597	13,417	4,753,307	44,695	15,040,904
1931	19,687	5,075,862	12,791	3,912,979	32,478	8,988,841
1932	8,546	2,092,721	4,584	898,979	13,130	2,991,700

Estimated world reserves of copper

By Arthur Notman
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In considering the amount of known reserves of copper in the world, the most significant fact is that no important copper-producing area has yet been exhausted. The Spanish district Rio Tinto, known to have produced from the days of the Phoenicians, is still active. The Mansfeld area, in Germany, has a recorded production extending continuously from the 13th century. In Cornwall, though production has ceased, substantial amounts of copper are still known to exist, but the metal cannot be produced in competition with that from more favorable areas. The reduction in the average grade of ore that can be treated has played and will continue to play an important part in expanding reserves of recoverable copper of the world.

There is wide room for choice in defining reserves of metal in the ground, but certain general limitations are readily recognizable. The human race has a real curiosity about the total amount of copper contained in the earth, but practically it is mainly concerned as to where copper can be obtained most readily, in what amount, and at what cost. Secondly, it is concerned as to the relation between known supplies and its current and prospective needs; and thirdly, as to whether the known reserves are keeping pace with consumption—that is to say, whether it is finding more or less new reserves than it is consuming. To answer these questions briefly for the moment, it may suffice to say that the known reserves of copper are probably greater now with respect to current consumption, or even the maximum rate of 1929, than at any previous period in the world's history—certainly greater than at any time in the last century. Discovery has far more than kept pace with rapidly increasing demand. This is borne out by the recent tendency to restrict the movements of the metal in world trade by tariff regulation.

There are four major known sources of supply in the world at present. In the order of their importance as gaged by past production they are (1) the Rocky Mountain and Great Basin area of the United States; (2) the west slope of the Andes in Peru and Chile; (3) the central plateau of Africa in the Belgian Congo and Northern Rhodesia; (4) the pre-Cambrian shield area of central Canada and its extension into northern Michigan. These areas contain about 95 percent of the total known reserves.

Table 1, prepared by the American Bureau of Metal Statistics, gives the latest official estimate of reserves of most of the principal copper-producing companies of the world.

TABLE 1.—*Copper-ore reserves as officially reported*

Company	Situation of mines	Ore reserves				Copper produced in 1929 (tons)[a]
		Year	Ore (tons)	Average grade (percent)	Copper (tons)	
United States and Mexico:						
Bagdad	Arizona	1930	48,000,000	1.20	576,000	....
Consolidated Coppermines	Nevada	1932	35,000,000	1.10	385,000	11,366
Inspiration	Arizona	1932	69,010,770	1.37	945,500	53,654
Miami	Arizona	1933	85,439,180	.96	817,500	29,421
Nevada Consolidated	Nevada, New Mexico, and Arizona	1930	300,000,000	1.47	4,410,000	133,137
Old Dominion	Arizona	1931	2,000,000	2.00	40,000	9,472
Phelps Dodge	New Mexico, Arizona, and Mexico	1932	388,146,550	1.13	4,386,100	173,195
United Verde Extension	Arizona	1931	360,000	[b]7.00	25,200	29,589
Utah	Utah	1930	640,000,000	1.07	6,848,000	148,313
Canada:						
Abana	Quebec	1930	477,200	2.70	12,900	....
Falconbridge	Ontario	1932	2,920,457	.93	27,200	....
Granby Consolidated	British Columbia	1931	14,062,761	1.81	254,500	30,427
Hudson Bay	Manitoba	1930	18,000,000	1.71	307,800	....
International Nickel	Ontario	1932	203,909,973	[b]2.00	4,078,200	[c]35,000
Noranda	Quebec	1933	22,450,000	2.77	622,800	25,813
Sherritt-Gordon	Manitoba	1932	4,800,000	2.50	120,000	....
Waite-Ackerman-Montgomery	Quebec	1931	467,350	6.00	28,000	1,100
Cuba and South America:						
Matahambre Mines	Cuba	1932	996,396	4.75	47,300	15,740
Andes	Chile	1924	137,400,000	1.51	2,074,700	81,332
Braden	Chile	1931	225,996,000	2.18	4,926,700	88,163
Chile Exploration[d]	Chile	1921	688,629,889	2.12	14,599,000	149,788
Africa:						
Katanga	Belgian Congo	1930	85,979,000	6.41	5,512,000	151,006
Baluba	Northern Rhodesia	1931	21,000,000	3.47	728,700	....
Chambishi	Northern Rhodesia	1931	25,000,000	3.46	865,000	....
Kansanshi	Northern Rhodesia	1931	8,000,000	4.50	360,000	....
Mufulira	Northern Rhodesia	1931	116,000,000	4.41	5,116,000	....
N'Changa[e]	Northern Rhodesia	1932	141,780,000	4.63	6,564,400	....
N'Kana[e]	Northern Rhodesia	1932	127,000,000	4.00	5,080,000	....
Chingola[e]	Northern Rhodesia	1932	2,000,000	7.00	140,000	....
Roan Antelope	Northern Rhodesia	1931	108,000,000	3.44	3,715,200	....
Messina	Transvaal	1932	1,325,433	2.61	34,600	7,529

Other:						
Boliden	Sweden	1932	6,600,000	[b]2.00	132,000	....
Indian Copper	India	1931	691,942	3.25	22,500	1,832
Mount Lyell	Australia	1932	4,799,931	2.74	131,500	9,903
			3,536,242,832	2.09	73,934,300	1,185,780

[a] The production in 1929 is given in order to afford an idea of the number of years of prospective production, the 1929 rates being given as more or less representative of the maxima.

[b] Approximate.

[c] Estimated.

[d] The last publication of ore reserves of Chile Exploration Co. was made in 1921. Since then additional ore has been developed but not estimated.

[e] Rhokana Corporation.

With the exception of the Chile estimate of 1921 and the Andes estimate of 1924, the figures given in table 1 are all of sufficiently recent date to indicate little if any need for official modification. However, A. B. Parsons, secretary of the American Institute of Mining and Metallurgical Engineers, in his recent book "Porphyry coppers," published in 1933 by the Institute, lists the reserves of porphyry copper under date of 1929 as follows:

TABLE 2.—*Ore resources of porphyry copper mines*

Mine	Date of estimate	Ore (tons)	Copper	
			Percent	Tons
Utah	December 1929	640,000,000	1.07	6,848,000
Morenci	December 1930	379,349,000	1.02	3,869,000
Nevada	December 1929	[a] 67,963,000	[a] 1.48	1,006,000
Braden	....do	234,798,000	2.18	5,119,000
Miami	....do	97,400,000	.95	925,000
Ray	....do	[a] 85,103,000	[a] 1.65	1,408,000
Chino	....do	[a] 125,000,000	[a] 1.40	1,750,000
Inspiration	February 1926	96,000,000	1.40	1,344,000
Chuquicamata	December 1922	684,259,000	2.12	14,506,000
New Cornelia	May 1929	113,262,000	1.25	1,420,000
Copper Queen	December 1929	[b] 23,500,000	1.63	383,000
Andes	December 1924	137,400,000	1.51	2,074,000
		2,684,034,000	....	40,652,000

[a] Private communication from management.
[b] Includes high-grade ore.

Morenci, New Cornelia, and Copper Queen are all part of the present Phelps Dodge Corporation. Parsons gives them a combined tonnage of 492,611,000 tons, with an average of 1.10 percent of copper and a total copper content of 5,672,000 tons. This is 1,285,900 tons more metal than the amount given for the Phelps Dodge Corporation by the American Bureau of Metal Statistics, whose figure was presumably intended to include not only the porphyry deposits owned by the corporation but the much richer limestone replacement deposits owned by it in Bisbee, Arizona. It is true that some of the reserves included by Parsons have been mined since 1929. The Butte deposits of the Anaconda and the Michigan deposits are not included in his table, as there are no published official estimates. The Butte area stands second in the list of producers of the United States; Michigan for many years stood first and even now ranks seventh or eighth.

The Engineering and Mining Journal for February 23, 1931, published an estimate of world reserves by Col. P. E. Barbour showing an aggregate of 88,542,000 tons of copper. The main increase over that shown in table 2 was 316,000,000 tons of 4 percent ore, or 12,640,000 tons of copper, developed by the Chile Copper Co. since 1921, the date of the last official estimate. Since the 1931 estimate for the Mufulira, in Northern Rhodesia, that company has published (in June, 1932) an estimate of 162,000,000 tons of 4.12 percent ore, or 6,706,800 tons of copper, an increase of 1,590,800 tons. This increase is equal to 75 percent of all the copper mined in the world in the two years 1932 and 1933. No doubt similar increases might be registered for the two other important Rhodesian companies, if there were any object in doing so.

If we take into consideration the probable reserves in the Butte and Lake Superior districts in this country and the unreported reserves in Russia and Japan, it is safe to say that the total known world reserves are of the order of 100,000,000 tons of copper. The average rate of consumption for the last 13 years, according to the American Bureau of Metal Statistics, has been about 1,450,000 tons. At that rate, even if no more copper were found, the reserves would last for 69 years. It is probable, therefore, that for some years to come only the lower-cost mines will find a profitable outlet for their copper except where free market conditions are interfered with by tariffs, quotas, etc.

Since 1800 the United States has absorbed about 20,000,000 tons of copper, and the estimated reserves of the domestic mines amount to about 20,000,000 tons. In other words, for each person of this country there is about 300 pounds of the metal in use and as much more available in the ground. This would seem to be an entirely adequate supply and more than adequate assurance for the future.

The domestic industry is now equipped to produce annually 1,200,000 tons of new copper, or 19.2 pounds per capita, and has a potential capacity to recover 250,000 tons of scrap, or 4 pounds per capita. In 1929, according to the American Bureau of Metal Statistics, the country consumed 18.42 pounds per capita; in 1932 the consumption dropped to 5.39 pounds, an amount less than 25 percent of the potential supply from domestic sources alone.

Beyond all these figures lies the fact that most of the proved districts contain many more millions of tons of the metal in material too low in grade to have been profitable in the past but ready at any time for extraction when costs can be reduced or demand has increased to a point beyond the ability of the cheaper sources of supply to satisfy the needs.

When the day arrives that the inhabitants of South America, Asia, and Africa require facilities similar to those now in use in the industrial nations of the world, they may replace the apparently waning requirements of the nations of western Europe and North America for new copper. At least it can be said that there is no present shortage of supply, and no prospect of one for several decades to come.

If we take into consideration the probable reserves in the Butte and Lake Superior districts in this country and the unreported reserves in Russia and Japan, it is safe to say that the total known world reserves are of the order of 100,000,000 tons of copper. The average rate of consumption for the last 15 years, according to the *American Bureau of Metal Statistics*, has been about 1,450,000 tons. At that rate, even if no more copper were found, the reserves would last for 69 years. It is probable, therefore, that for some years to come only the lower-cost mines will find a profitable outlet for their copper except where free market conditions are interfered with by tariffs, quotas, etc.

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NORTH AMERICA

The geologic features of the occurrence of copper in North America

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Introduction

Copper is of such widespread natural occurrence in North America and there are so few metal-mining districts that have not contributed to its production that it is obviously necessary in any brief general treatment of the geology of the copper deposits of the continent to restrict the discussion to the districts in which copper is the dominant metallic product. Otherwise the summary would be unreasonably long.

The copper deposits of North America may be classified in various ways—with respect to form, genesis, geologic age, distribution, and distinctive features of character or occurrence. On the whole, an areal grouping will probably be most satisfactory. To some extent this will coincide with a classification based on the form or character of the deposits, but there will be notable exceptions. Classification, after all, is merely a human expedient for systematizing description and for facilitating studies of origin. It is essentially artificial and sets up class distinctions, the legality of which, at least so far as ore deposits are concerned, Nature does not recognize.

The present paper discusses the geology of the copper deposits of North America in accordance with the following general grouping:

1. Copper deposits of the Appalachian belt.
2. Copper deposits of the pre-Cambrian Canadian Shield.
3. Copper deposits of the Lake Superior region.
4. Copper deposits of Butte, Montana.
5. Copper deposits of the southwestern United States and northern Mexico.
6. Copper deposits of the Pacific coast north of Mexico.

Copper deposits of the Appalachian belt

The term "Appalachian belt" is here used to designate the chain of mountains along the Atlantic seaboard, extending from Alabama into Newfoundland, which came into existence in consequence of the folding and faulting that culminated in Permian time. This unit, corresponding in part to the Appalachian Mountains of today, is less extensive than the Appalachian region of Keith (1, pp. 330–332), which, as a structural entity, he regards as extending far westward into eastern Arizona, including the Ozark dome and the Arbuckle and Ouachita Mountains.

Within the United States the Appalachian province, from central Alabama to southern New York, is generally divisible into four longitudinally coextensive units. These, from east to west, are (1) the Piedmont Plateau, composed mainly of pre-Cambrian or early Paleozoic metamorphic rocks, including gneisses, extensively invaded, in Permian time, by granite and other igneous rocks; (2) the Appalachian Mountains, of which the dominant structural and geomorphic feature is the great compound Blue Ridge geanticline, composed of rocks similar to those of the Piedmont Plateau, but with a larger proportion of relatively unmetamorphosed early Paleozoic sediments; (3) the Appalachian Valley, eroded along a belt from 40 to 125 miles wide, of closely folded Paleozoic sedimentary rocks, mainly calcareous; and (4) the Appalachian (Cumberland) Plateau, which, from its eastern escarpment, overlooking the Appalachian Valley, slopes gently westward in general conformity with the inclination of the underlying Paleozoic beds.

Although the Appalachian belt is one of the world's classic examples of folded structure, faulting, both normal and thrust, has played a large part in its tectonic development (1, 2).

The Appalachian copper deposits, except those at Ducktown, Tennessee, are of slight present economic importance, and there is little chance of improvement in this respect in the next few decades. The relative insignificance of these deposits industrially may be seen from the following statements. The entire output of copper in the United States in 1931 was 1,042,711,178 pounds. Of this, 21,911,638 pounds was given by the United States Bureau of Mines as "undistributed." This included the undivulged production from Tennessee. In 1928 the total production from Tennessee, mainly or entirely from Ducktown, was 16,374,261 pounds. If it is assumed that the output from Ducktown in 1931 was roughly 16,000,000 pounds, this would leave about 6,000,000 pounds from all undesignated sources, inclusive of the Appalachian mines other than those at Ducktown.

The most comprehensive general account of these deposits has been given by Weed (3), who divides them into six types, as follows:

1. Ducktown type. Pyrite lenses and veins in crystalline schists. Occurs at Ely, Vermont; Ore Knob, North Carolina; southwest Virginia; Ducktown, Tennessee; Milan, New Hampshire; Davis, Massachusetts; and Stonehill, Alabama.

2. Copper quartz-vein type. Quartz veins containing metallic sulphides. (*a*) Virgilina variety; quartz veins with glance and bornite; occurs at Copper Knob (Gap Creek), North Carolina. (*b*) Gold Hill variety; silicified schists, containing chalcopyrite and pyrite, with ore shoots of quartz and chalcopyrite; occurs in veins of North Carolina and Virginia gold belt. (*c*) Seminole variety; zone of pyritized schists, carrying local shoots of high-grade ores.

3. Carolinian type. Bands of amphibolite traversing mica schists and carrying chalcopyrite and pyrite disseminated through the rock or gathered in bunches or, more commonly, deposited in the gray gneiss alongside. Occurs at Elk Knob, Way-ye-hutta, and Peach Bottom, North Carolina, and at New Haven, Connecticut.

4. New Jersey type. Impregnated shale and sandstone adjacent to trap masses; in part in the trap. Occurs at Somerville, Arlington, and Griggstown, New Jersey, and at Leesburg and Orange, Virginia.

5. Pahaquarry type. Devonian sandstones impregnated with copper ores; and shales, etc., of Coal Measure regions with occasional ore; not rare but insignificant in amount.

6. Blue Ridge (Catoctin) type. Bunches and joint fillings in the surficial portions of the basaltic rocks (Catoctin schist) of the Blue Ridge region.

The foregoing list is not all-inclusive and, in certain respects, is open to criticism or modification. Many of the examples cited are practically negligible economically. Attention will be given here only to a few of the more important types and localities.

Ducktown type

The Ducktown district, in which are the principal deposits of the Ducktown type, is mainly in the southeast corner of Tennessee but extends a short distance across the State boundary, into northern Georgia. It is within the Blue Ridge division of the Appalachian Mountains. The district has been fully described by Emmons and Laney (4), whose paper contains a full bibliography on the area.

The ore deposits occur in the schistose rocks of the Great Smoky formation, which are metamorphosed sediments of Lower Cambrian age. The only igneous rocks recognized in the district are dikes of gabbro, of probably late Paleozoic age. There were apparently two main epochs of folding and metamorphism—one at the end of the Ordovician period and one at the end of the Carboniferous. Less intense deformation of undetermined post-Carboniferous age represents a third epoch.

The ore bodies of Ducktown are chiefly curved tabular masses such as would result from the replacement of particular beds, after complex folding. They are chiefly faulted domes and anticlinoria, complicated by subsidiary carinate folds. The hypogene ore consists principally of pyrrhotite, pyrite, chalcopyrite, sphalerite, bornite, actinolite, calcite, pyroxene, tremolite, quartz, garnet, chlorite, specularite, and magnetite.

Various views have been advanced as to the origin of the Ducktown ore bodies. Emmons (4, p. 64) concludes that they have been formed by the replacement of lenticular bodies of limestone, after these had been folded and faulted with the Great Smoky formation, of which they are stratigraphic parts. He believes that the source of the mineralizing solutions was some deep-seated granitic mass, similar to exposures known about 12 miles away.

In the early period of development most of the copper from the Ducktown district was derived from a zone or layer of high-grade chalcocite ore, commonly from 3 to 4 feet thick. The top of this layer was roughly coincident with the underground-water table and lay about 100 feet below the highest ore outcrops. Although chalcocite enrichment probably took place during the development of the Tertiary peneplain, of which remnants are recognizable in the region, the chalcocite mined was deposited during the period of erosion that followed the uplift of that peneplain. The process of enrichment is fully discussed by Emmons in the report cited and also by Gilbert (5). In the thinness, definiteness, and regularity of the supergene chalcocite zone, the Ducktown deposits present a marked contrast to the enriched copper deposits of the arid southwestern United States, doubtless because of the relatively humid climate of Ducktown, the stability of the water table, and the presence of abundant pyrrhotite in the ore.

The copper deposits of Maine and of Milan, New Hampshire, included by Weed in the Ducktown type, should, in accordance with their description by W. H. Emmons (6), probably be regarded as a separate type. These deposits lie in a low plateau, floored by closely folded metamorphic, sedimentary, and igneous rocks, ranging in age from pre-Cambrian (?) to Devonian. The deposits occur in schists, which are in part metamorphosed siliceous shales and argillaceous sandstones (Ellsworth schist) and in part metamorphosed andesitic and rhyolitic lavas and associated clastic rocks (Castine formation). These rocks are probably pre-Cambrian. The ore bodies are chiefly more or less lenticular, veinlike masses of pyrite, with some chalcopyrite, pyrrhotite, magnetite, arsenopyrite, bornite, chalcocite, and a little sphalerite and galena. The gangue minerals are quartz, chlorite, muscovite, and biotite. The ore masses, probably of post-Cambrian and pre-Silurian age, have undergone at least a considerable part of the contortion and metamorphism that have affected the enclosing rocks, and in this respect they differ from those of Ducktown. Moreover, they appear to have been originally replacement veins along fissures and not to have replaced limestone. The shipping ore from the Milan mine, according to Emmons, carries about 2.25 percent of copper, 7.3 percent of zinc, 1.6 percent of lead, and about $1.50 in gold and as much as 2 ounces of silver to the ton. These ore deposits are not clearly related to any particular intrusive rock, although Emmons suggests that some of them may be genetically connected with granites of late Silurian or early Devonian age.

Virgilina type

Of Weed's second type (copper quartz veins), the Virgilina variety is the only one to which particular attention will here be given. The Gold Hill variety includes deposits that are as much gold veins as copper veins, and the Seminole variety is of very slight economic importance.

The best-known and probably the only economic examples of the Virgilina type are those of the district from which the name is derived. The Virgilina district extends across the line between Virginia and North Carolina, about 160 miles west of Norfolk, Virginia, near the eastern border of the Piedmont Plateau. The rocks of the district are greenstone schist and quartz-sericite schist, derived respectively from pre-Cambrian or early Paleozoic andesite and rhyolitic lavas, with associated tuffs. The tuffs of andesitic affinity grade in places into sandstones and conglomerates. These rocks are cut by intrusions of granite and gabbro. The structure, according to Laney (7), is probably that of a closely compressed syncline with axis striking north-northwest. The beds dip 70°–80° E.

The copper deposits occur as steeply dipping veins, which generally strike a little more northerly than the adjacent schists. Some of the veins are 20 feet wide and may be traced for 4 or 5 miles along their strikes. Most of them are markedly lenticular, and a banded structure is common. The vein filling is chiefly quartz, carrying bornite and chalcocite, with rarely a little chalcopyrite. Locally, epidote, calcite, and albite may be present as gangue minerals.

Laney concludes that the ores are probably related in origin to the intrusion of the granite, although the fact that they are confined to the more basic facies of the greenstone schists is referred to as indicating some genetic relationship, not definitely stated, between the copper ores and the basic schists. He regards the bornite and the greater part of the chalcocite as of contemporaneous, hypogene deposition. The deepest mines at the time of Laney's study were less than 500 feet deep, and probably there has not since been any notable amount of work done below that depth.

Catoctin type

The native copper deposits of the Catoctin type are of no economic importance but are of considerable interest with respect to genesis. These deposits are distributed along the Blue Ridge region of the Appalachians from southern Pennsylvania into Virginia. They lie generally between the folded Cambrian and Ordovician sediments on the west and areas of Cambrian quartzite and Triassic rocks on the east. The contacts between the copper-bearing rocks and the Paleozoic rocks on the west are in part due to thrust faulting; the contacts on the east are in part due to normal faulting.

The copper-bearing rocks are pre-Cambrian basaltic lavas which have been altered to greenstones and in part to schists. In some places, as in South Mountain, Pennsylvania, the basic lavas are associated with metarhyolites. Augite and olivine are still recognizable in some of the ancient basalt, but there has generally been an extensive development of chlorite, epidote, and secondary quartz. The basic flows, of which two have been recognized, are strongly folded and are cut by thrust faults with low dips to the east. Joints are numerous, and the copper is generally associated with zones of vertical sheeting.

Native copper is the characteristic ore mineral, in places accompanied by cuprite and by the usual carbonates due to oxidation. There are no well-defined veins. The copper occurs disseminated through zones of jointing and epidotization. The deepest exploration, by shafts, is about 300 feet.

Some deposits of the same type are reported to occur in the Piedmont Plateau, in Virginia.

Most geologists who have studied these deposits have concluded that the copper was derived from the basic lavas themselves. Weed regarded the process of concentration as essentially superficial—a consequence of weathering. Watson (8), however, has more recently suggested that, although the copper was derived from the lavas, it was extracted and concentrated as native copper by hot, hypogene solutions in pre-Cambrian time. He accounts for the deposition as native metal by suggesting that the sulphur in the ore-bearing solutions was oxidized by the ferric iron in the epidote, thus appealing to a process similar to that advanced to account for the native-copper deposits of Michigan and Bolivia. The explanation offered by Watson, however, appears to be scarcely consistent with the contemporaneous deposition of copper and epidote, which is apparently indicated by the published descriptions of these interesting though noneconomic deposits.

New Jersey type

The deposit near Bristol, Connecticut, on which the most recent publication is that of Bateman (9), is notable rather for the mineralogic specimens of chalcocite which it has yielded than for its output of copper. It would appear to fall most nearly into the New Jersey type of copper deposit—impregnated Triassic shale and sandstone near trap masses (10). The mine was worked as early as 1837 but has been idle since 1895. According to information gathered by Bateman, the ore occurs partly within a strong fault along which Triassic sandstone on the southeast has been dropped against schist of supposedly Ordovician or Silurian age on the northwest. The copper sulphides, mainly bornite and chalcocite, apparently occurred as irregular veins in the fault zone and as veinlets and disseminated particles in certain of the Triassic sandstone beds adjacent to the fault, in the hanging wall. Bateman concludes that the chalcocite and bornite are hypogene, that the deposition took place during the Triassic, and that it probably was genetically connected with the intrusion of the trap during that period.

In southeastern Quebec the Appalachian Mountains are represented by two systems of anticlinal ridges from 20 to 25 miles apart, which, together with the intervening valley and adjacent territory on both sides, are composed of closely folded, more or less schistose sedimentary and igneous rocks of pre-Cambrian and early Paleozoic age. Most of the copper deposits occur within or close to the two main belts of schistosity.

In Nova Scotia are unimportant deposits of Triassic age similar to those in New Jersey (11).

Summary

From the foregoing outline it appears that the Appalachian copper deposits, although for the most part of slight economic importance, are of diverse character and of considerable scientific interest. The principal periods of deposition seem to have been in early Paleozoic and Triassic time. The deposits of the Catoctin type, according to divergent views of origin, may be as old as the pre-Cambrian or as young as the Quaternary. Although the copper deposition was presumably associated in some manner with igneous activity, the relation is neither direct nor obvious. The details of the connection between igneous intrusion and copper-ore deposition have, in this region, been matters of inference or conjecture rather than of demonstration, and, for the ores of the Catoctin and New Jersey types, the parts played by hypogene and supergene processes are still in question.

Copper deposits of the pre-Cambrian Canadian Shield

The term "Canadian Shield" is a familiar designation for the great U-shaped area of pre-Cambrian rocks which stretches northward from the vicinity of the Great Lakes, on both sides of Hudson Bay, into the Arctic regions. It is in general a lake-dotted peneplain of low relief but attains altitudes of at least 5,000 feet along the northern coast of Labrador.

The rocks composing the Shield fall into two main divisions. The older division is also of dual character, being composed of an older series, the Keewatin, consisting mainly of ancient lavas, largely basic, with a minor proportion of sedimentary rocks, and a younger series, the Timiskaming, consisting of sedimentary rocks. Overlying the older division (Ontarian of Lawson) with great unconformity is the Huronian system of sedimentary rocks.

In addition to these rocks, the region contains enormous areas of granite and granite gneiss, with associated intrusive rocks. According to Lawson (12), these fall mainly into two groups—those intruded at the end of Keewatin time (Laurentian revolution) and those intruded at the end of the Huronian (Algonkian revolution). The Laurentian intrusions have, so far as known, obliterated the original base of the Keewatin.

Occurrences of copper ore are known at many widely scattered localities over the Canadian Shield, but only three groups are of sufficient economic importance to demand attention in the present review. These are the nickel-copper deposits of Sudbury, the copper deposits of Rouyn, and the deposits of the Schist Lake area of Manitoba and Saskatchewan.

Nickel-copper deposits of Sudbury

The nickel-copper deposits of Sudbury are in the Province of Ontario, about 35 miles north of Georgian Bay, Lake Huron. These unique and highly important deposits, the world's chief source of nickel, are described elsewhere in this volume. It must suffice here to recall that the dominant geologic feature of the district is a spoon-shaped intrusive sheet of "nickel eruptive" which has an elliptical outcrop about 37 miles long and 17 miles in its shorter diameter. The average thickness of the sheet has been estimated at about a mile. The sheet is mainly composed of what has generally been termed "norite," but this changes upward, by gradation or otherwise, into what has commonly been designated "micropegmatite." The norite rests, so far as is observable, on an ancient complex of granites and gneisses (of Laurentian age in part), schists, metamorphosed sediments (Sudbury series), and various acidic and basic eruptives. At least a part of the granite and granite gneiss of this complex is regarded by some geologists as having been intruded after the norite. Within the spoon, in synclinal attitude, are sedimentary rocks, probably of Animikie age, with a total maximum thickness estimated as between 9,000 and 10,000 feet.

The copper-nickel ores occur near the base of the norite, largely within that rock but partly in the underlying rocks. They consist essentially of pyrrhotite, pentlandite, chalcopyrite, pyrite, and small quantities of magnetite. The general order of deposition has been magnetite, pyrrhotite, pentlandite, and chalcopyrite, with pyrite not definitely placed in the sequence.

The origin of these deposits has been earnestly discussed, and the literature relating to them is voluminous (13, 14, 15, 16, 17, 18, 19, 20, 21). The evidence, variously interpreted by different investigators, appears to indicate that the Sudbury deposits are high-temperature metasomatic replacement deposits and that their constituents came from the norite magma. Their age is pre-Cambrian.

Rouyn district

The town of Rouyn is in western Quebec, about 30 miles south-southeast of Lake Abitibi and 24 miles east of the Ontario boundary. It lies a little east of the middle point of a line drawn from the southern tip of Hudson Bay (James Bay) to the north shore of Georgian Bay, Lake Huron.

The Rouyn district shows the major twofold division of pre-Cambrian rocks characteristic of the Canadian Shield, with the two divisions separated by a profound unconformity. The older group comprises the Keewatin, composed of ancient lavas of great diversity, ranging from basalt to rhyolite, with some metamorphosed sediments, overlain, with probable unconformity, by the Timiskaming sedimentary series. Above the major unconformity of the region come the Huronian and later sediments. Intrusive rocks of many kinds, but predominantly granitic and granodioritic, cut the Timiskaming and older rocks (22).

The copper deposits occur in the Keewatin rocks. The ore bodies are irregular masses, of stout or rotund form, to which the terms "lens" and "lenticular" are only roughly applicable. They consist commonly of pyrite and pyrrhotite, with a varying proportion of chalcopyrite. Some also contain sphalerite and magnetite. The proportions of these minerals vary greatly in different deposits. Moreover, some are virtually solid sulphide masses, whereas others are merely country rock carrying disseminated sulphides in uneconomic quantity. They range from those of very small size to great masses several hundred feet long and 200 feet wide.

Economically the deposits may be divided into two classes—those which consist chiefly of iron sulphides and those which contain industrial quantities of copper and zinc sulphides. This grouping, according to Cooke, James, and Mawdsley (22), corresponds also to a difference in age, the copper and zinc sulphides having been introduced after the deposition of the iron sulphides, although there is some late-stage pyrite.

The rocks in which the sulphide bodies occur are all siliceous lavas (rhyolites and dacites) or corresponding pyroclastic rocks and tuffs. They have been extensively silicified and chloritized near the sulphide masses. This alteration, there is some evidence to indicate, was effected mainly by the solutions that deposited copper and zinc sulphides rather than by those that deposited principally iron sulphides. The chalcopyrite apparently followed closely upon chloritization and replaced the chlorite.

The Rouyn copper deposits were formed by progressive hydrothermal replacement at sites rendered favorable by the character of the rock and the presence of fissures. The depositing solutions were hypogene and, in addition to the metals and sulphur, carried large quantities of silica and magnesia. Pyrite and pyrrhotite were deposited first, followed by chalcopyrite and sphalerite. Cooke, James, and Mawdsley regard the ore-depositing solutions as unquestionably of magmatic origin and are inclined to relate the iron-bearing solutions to the magma that supplied the various bodies of soda-rich syenite porphyry, of post-Timiskaming age, present in the district. Whether the copper-bearing solutions emanated from the same magma is a question that they do not undertake to answer.

The principal copper mine of the district is the Horne.

Schist Lake region

Of the deposits of the Schist Lake region in Manitoba and Saskatchewan, two, the Mandy and the Flin Flon, are of present outstanding importance. The Mandy mine is on the west shore of the northwest arm of Schist Lake, about 70 miles north of The Pas and 400 miles northwest of Winnipeg, close to the western boundary of Manitoba. The Flin Flon mine, on the lake of the same name, is about 4 miles north of the Mandy. These deposits have been described by various writers, among whom may be mentioned Spurr (23), Bruce (24), and Hanson (25).

The Manitoba deposits occur in pre-Cambrian rocks, near the western border of the Canadian Shield. The old rocks, the Amisk series, consisting of lavas, tuffs, agglomerates, and derived schists, are probably the equivalent of the Keewatin farther east. They are succeeded by gneisses and pre-Cambrian sedimentary rocks, but the copper deposits are confined to the Amisk volcanics. There appear to have been two periods of granitic intrusion—an earlier, represented by the Cliff Lake granite porphyry, following the deposition or eruption of the prototypes of the Kisseynew gneisses, which overlie the Amisk volcanics, and a later, represented by the Kaminis granite, of which the intrusion, as great batholiths, apparently marked the end of the pre-Cambrian (Algoman revolution).

The ore bodies of the region are lenticular veins and masses in the Amisk volcanics. Two general classes have been distinguished by Hanson—those consisting chiefly of pyrite, chalcopyrite, and sphalerite and those consisting chiefly of pyrrhotite. The deposits of economic importance up to the present time belong to the first class. All represent mineralization along sheared or brecciated zones in the more or less schistose volcanic rocks.

The Mandy ore body is an irregular lens 225 feet long and as much as 40 feet wide, with relatively narrow, veinlike projections from its ends. It strikes with the enclosing chlorite schists and greenstones, a little west of north, and dips 75°–80° E. It consists of nearly pure pyrite near the walls but encloses a nuclear mass of banded sphalerite and chalcopyrite. It is believed by both Bruce and Hanson that an original hydrothermal replacement of the schist by pyrite was followed by successive fracturing and deposition of sphalerite and chalcopyrite, the final deposit being mainly chalcopyrite. Arsenopyrite and galena are also reported in the ore. Bruce believes that the source of the ore-bearing solutions was the magma of the younger or Kaminis granite. Hanson favors a similar granitic source but is not definite as to the age of the granite. Spurr, in accordance with his well-known views, regards the Mandy ore body as formed by a series of intrusions of "plastic sulphides" (23, p. 116).

At the Flin Flon mine the ore occurs in the same rocks as the Mandy ore body but is less complex in internal structure and in the distribution of the sulphides. It is also of lower grade. It is reported to contain about 18,000,000 tons of ore carrying 1.71 percent of copper and 3.45 percent of zinc. The ore replaces the greenstone along a great shear zone. It has been explored for a length of over 2,500 feet at the surface and is known to be 1,000 feet long at a depth of 900 feet. It extends to a depth of at least 2,500 feet and is 75 feet in maximum width. It strikes northwesterly with the schists and dips 60°–70° NE. The ore at Flin Flon is chiefly pyrite, with sphalerite, chalcopyrite, and some magnetite. The only gangue material consists of small blebs of quartz and inclusions of country rock. Virtually all geologists who have studied the Flin Flon deposit, including Spurr, consider it as having been formed by hydrothermal replacement of the sheared schist. The opinions recorded as to the source of the depositing solutions of the Mandy ore body apply also at Flin Flon.

Other deposits

Smaller pyritic deposits, more or less resembling those of Manitoba and occurring in various parts of the Canadian Shield, are briefly described by Hanson in the paper cited, and similar but undeveloped and low-grade deposits in the Manitoba-Saskatchewan region are mentioned by Spurr (23, p. 123).

About 50 miles northeast of the Flin Flon deposit, in northern Manitoba, is the Sherritt-Gordon copper-zinc deposit (26). This is a more or less lenticular mass of pyrrhotite, chalcopyrite or chalmersite, sphalerite, and marcasite, with a gangue of quartz, amphibole, chlorite, garnet, biotite, and scapolite, formed by the replacement of folded gneiss (Kisseynew gneisses). The copper-zinc deposition is supposed to have been genetically connected with granitic intrusions in the gneiss.

Still farther north, on the Coppermine River, between Great Bear Lake and Coronation Gulf, are deposits of chalcocite and native copper in pre-Cambrian amygdaloidal basalts. According to Gilbert (27), although native copper is widely disseminated through the basalts, it is probably not present in economic quantity. The more promising deposits are veins carrying chalcocite, with a little bornite and chalcopyrite. Gilbert, while recognizing the possibility of some genetic connection between the basaltic magma and the vein deposits, concludes that there is no direct relation between these deposits and the visible amygdaloidal flows.

The Canadian Shield is an area in which ore bodies are not easily found, and it is probable that in that vast region there are still many masses of copper ore which have not been discovered.

Copper deposits of the Lake Superior region

Although deposits of native copper are known elsewhere on the globe, those of northern Michigan are unique, among deposits of this type, for their size and productivity. They have yielded, since 1845, more than 7,500,000,000 pounds of copper. As these deposits are practically confined to a single district, that of the Keweenaw Peninsula, which is adequately described elsewhere in this volume, they will be accorded much briefer treatment in the present paper than is commensurate with their scientific interest and economic importance. The information presented has been drawn chiefly from the most recent comprehensive report on the district, that by Butler and Burbank and their collaborators (28).

The outstanding geologic features of the Keweenaw Peninsula are a thick series of basic lava flows, reddish felsitic conglomerates, and sandstones, which strike generally in a northeasterly direction and dip northwest. These rocks, constituting the Keweenawan series, of pre-Cambrian (Algonkian) age, have been upthrust from the northwest over Upper Cambrian sandstone. The basaltic flows, in part amygdaloidal, are some thousands of feet in total thickness and are interbedded with the conglomerates. The upper part of the series is mainly sandstone. Intrusive rocks, in relatively small volume, are found in the Keweenawan series. They have been classed as gabbro, quartz porphyry and felsite, and basic dikes.

The copper occurs at various horizons in the Keweenawan series, chiefly in the amygdaloidal or brecciated tops of the basalt flows and in certain of the felsitic conglomerates. To a minor extent it also occurs in fissures that cut through the basalts and conglomerates. With the native copper are present, in much smaller but significant quantities, chalcocite, bornite, and various arsenides of copper. A characteristic assemblage of gangue minerals is associated with these ore minerals. Chlorite, feldspar, epidote, and pumpellyite were formed generally in advance of the copper deposition, which was accompanied by the formation of quartz, calcite, prehnite, and datolite. Laumontite, analcite, and some other minerals are younger than the copper.

Various opinions have been advanced to explain the origin of these remarkable deposits. These are fully reviewed by Butler and his associates, who conclude that the deposition was effected by hypogene solutions that emanated possibly from the magma of the Duluth gabbro and rose along the Keweenaw fault, which limits the Keweenawan series on the southeast. These solutions carried sulphur and in most districts would have deposited sulphide ores. The reduction to native copper, involving oxidation of the sulphur, they believe, was brought about by the oxygen of the ferric iron present in the conglomerates and particularly in the permeable tops and bottoms of the lava flows. Their theory, which is presented here in bare outline, is very fully developed in the report cited and is supported by such an array of facts that those who may not be ready to consider the problem closed must nevertheless accept their results until further, equally thorough and able study affords a reasonable basis for dissent.

In connection with the native-copper deposits of the Keweenaw Peninsula, it is of interest to note the occurrence on Susie Island, near the northwest shore of Lake Superior, of the economically unimportant veins of copper sulphides in calcite and quartz, described by Schwartz (29). Here, on the opposite limb of the syncline occupied by the western arm of Lake Superior, hypogene solutions deposited bornite, chalcocite, chalcopyrite, and pyrite, in contrast with the predominant native copper of the southeast limb of the same syncline.

Copper deposits of Butte, Montana

The region of the northern Rocky Mountains, in Montana and adjacent States to the south and west, is characterized by the widespread distribution of the Belt series of Algonkian sediments, overlain unconformably by Paleozoic rocks of Cambrian, Devonian, and Carboniferous age, which in turn are succeeded unconformably, in some localities, by Jurassic and Cretaceous sediments. These rocks have been vigorously folded and are cut by many faults, some of which are overthrusts of great magnitude.

The period of major deformation that appears to have ended the Cretaceous sedimentation was accompanied by the extensive intrusion of domelike masses of magma, which solidified as granite, diorite, and intermediate types. The age of these intrusive masses has not in all cases been determined. The largest of them, the batholith that contains the Butte copper deposits, which is exposed for a length of some 65 miles and a width of 15 miles, was believed by Weed to be of Miocene age (30, p. 29), but it is more probably late Cretaceous to Eocene (31).

The copper veins of Butte, which since the beginning of production, about 1868, have produced over 9,000,000,000 pounds of copper, occur in the quartz monzonite of the Boulder batholith, near its western margin, in a region of north-south block faulting on a large scale.

As the Butte district is elsewhere described in this volume, the present account is compressed to extreme brevity.

The fissures of the district have been divided by Sales (32) into seven classes, as follows:

1. Anaconda or east-west system. Ore-bearing.
2. Blue or southeast-northwest system. Ore-bearing.
3. Mountain View faults. Not ore-bearing.
4. Steward or southwest-northeast system. Ore-bearing.
5. Rarus fault. Not ore-bearing, except of ore dragged in from earlier fissures.
6. Middle faults. Not ore-bearing.
7. Continental fault. Not ore-bearing.

According to Weed and Sales, the fissures were formed at different periods and have the age relations indicated by the order of the foregoing list, the Anaconda fissures being the oldest. Ray (33), however, maintains that all the ore-bearing fissures were formed at the same time, although subsequent faulting and supergene enrichment have affected the northwest and northeast veins more strongly than the east-west veins. I concur in this opinion.

The Butte copper veins were formed by the filling of fissures, accompanied by considerable replacement of crushed quartz monzonite. They consist essentially of quartz, pyrite, chalcocite, bornite, and enargite, with smaller quantities of rhodochrosite, covellite, chalcopyrite, tetrahedrite, and tennantite. Supergene chalcocite has been an important source of copper above a depth of 1,200 feet, but the chalcocite below that depth is mainly hypogene. The Butte veins constitute a remarkably intricate complex, in which the splitting up of certain veins into brushlike aggregations of smaller veins, the so-called "horsetails," is one of the most extraordinary features.

In the Butte district the essentially copper-bearing veins, so far as outcrops are concerned, are limited to a relatively small area adjacent to the city of Butte, and this area is enclosed by a zone of predominantly zinc-lead-silver veins. Deep development has tended to show that this distinction is less indicative of two different sets of veins than of an upward and outward zoning from a deep-seated center of mineralization. In other words, sufficiently deep development on the stronger fissures of the zinc-lead-silver zone would probably reach the copper zone.

Geologists are generally in agreement that the Butte ores emanated from the magma which in part solidified as the Boulder batholith and that consequently they are of early to middle Tertiary age.

In connection with the description of the Butte deposits, inasmuch as both occur in the northern Rocky Mountain region of the United States, may be mentioned the copper deposits of the Encampment district, Wyoming, described by Spencer (34). These economically rather unimportant deposits occur (*a*) in pre-Cambrian rocks as the result of concentration of chalcopyrite in certain layers of hornblende schist before or during regional metamorphism; (*b*) as the result of contact-metasomatic replacement of hornblende schist by chalcopyrite; and (*c*) as deposits of chalcopyrite in fissured or fractured quartzite interbedded with the schist. The deposits are probably of pre-Cambrian age, although those in quartzite may possibly be younger.

Copper deposits also occur in the Belt series in the Bitterroot Mountains of northern Idaho and western Montana, but these are not of great present importance and cannot be described here.

Copper deposits of the southwestern United States and northern Mexico

The copper deposits of the vast region extending from Utah into Mexico and from the southern Rocky Mountains and Great Plains on the east to the Sierra Nevada and Gulf of California on the west occur under so great a variety of geologic conditions and are so diverse in character that it is difficult or impossible to characterize them briefly as a whole.

The region is one in which pre-Cambrian and Paleozoic rocks are most prominently displayed, although in Mexico sediments of Mesozoic age are abundant. Marine Tertiary sediments are generally lacking, but Tertiary intrusive and effusive igneous rocks are widespread, and to the intrusive rocks of probable Tertiary age is largely, though by no means exclusively, to be ascribed the deposition of the copper ores.

Although folded structure is by no means absent in this region, the larger and more conspicuous structural features, of later than pre-Cambrian origin, are the result of faulting. The relatively undisturbed post-Archean rocks of the Colorado Plateau contain no large deposits (35), but some copper ores, related to fissuring, have been mined at various localities in that region (36).

Of the copper deposits having obvious genetic relationship with the intrusive porphyry masses, the disseminated ores, or so-called "porphyry copper ores," constitute at present the most characteristic and productive type of the region. Among them may be mentioned those of Bingham, Utah; Ely, Nevada; Santa Rita (Chino) and Tyrone, New Mexico; Morenci, Bisbee (in part), Miami, Ray, Ajo, and Bagdad, Arizona; and Cananea (in part), Mexico. In practically none of the districts is the copper confined to the disseminated type of deposit, but in all but Bisbee and perhaps Cananea this type is now the principal source of the copper produced.

The characteristic feature of these deposits is the dissemination of the copper-bearing minerals through parts of the intrusive porphyry mass itself or through the adjacent rock into which the porphyry is intrusive, in the form of isolated crystalline specks or as small veinlets. The most common copper mineral is chalcocite, formed by the supergene enrichment of low-grade rock, or protore, containing disseminated pyrite and chalcopyrite. The deposits, consequently, are not of great vertical range but are limited downward by the depth to which solutions derived from the surface have been able to penetrate during the present or some earlier stage of erosion. The foregoing general statements require amplification or qualification with respect to particular districts, as will presently appear. As the principal districts yielding disseminated copper ores are individually described elsewhere in this volume, only such general outline of each will here be presented as may suffice to show wherein they conform to or depart from a common type.

Bingham

In the Bingham district, Utah (37, 38, 39), quartzites and limestones of Carboniferous age, with an aggregate thickness of about 10,000 feet, were invaded at some not definitely determinable post-Carboniferous time by irregular masses of quartz monzonite and quartz monzonite porphyry.

The copper ores occur as lenticular or irregular pyrometasomatic bodies in limestone and as disseminated deposits in the quartz monzonite. The massive replacement bodies were first worked, but these, now largely exhausted, have been in later years far surpassed in importance by the great body of disseminated ore worked by the Utah Copper Co. Both types of deposit are genetically related to the monzonitic intrusions.

The disseminated copper ore, of which there is about 514,000,000 tons averaging 1.15 percent of copper, occurs in the quartz monzonite as scattered crystal particles and small veinlets of chalcopyrite and bornite, in part altered to supergene chalcocite.

Ely

At Ely, Nevada (40), sedimentary rocks ranging in age from Ordovician to Carboniferous and comprising limestone, quartzite, and shale have been invaded by monzonite and monzonite porphyry. The intrusion has been doubtfully assigned to Jurassic time. There were later eruptions of late Tertiary rhyolitic rocks. The principal ore bodies, which are of the disseminated type, occur in the monzonite and have been formed by chalcocitic enrichment of pyrite-chalcopyrite protore. There has also been considerable mineralization of the limestones, but relatively little sulphide ore has been found in these rocks. The ore deposits at Ely are believed to be genetically connected with the intrusion of the monzonite. Supergene enrichment may have been in operation for a long period, possibly beginning before the eruption of the Pliocene lavas.

Santa Rita

In the Santa Rita district, New Mexico, sedimentary rocks, chiefly calcareous or dolomitic and ranging in age from Cambrian to Cretaceous, were intruded by a granodiorite porphyry stock which metamorphosed and mineralized the adjacent limestones and, after extensive fracturing, was itself mineralized in the part now exposed to view. Disseminated pyrite and chalcopyrite in the intrusive stock were enriched by supergene processes, with the development of chalcocite, and to this enrichment the value of the ore body is almost entirely due. The intrusion and hypogene mineralization probably occurred in Tertiary time, and oxidation and enrichment, probably interrupted for a time by the eruption of Tertiary lavas, have continued to the present day.

Tyrone

At Tyrone, New Mexico (41), the regional geologic relations are in general the same as at Santa Rita, but the intrusive rock, here classed as quartz monzonite porphyry, is enclosed in pre-Cambrian granite, which does not come to the surface at Santa Rita. The ore bodies occur both in the granite and in the monzonite porphyry and are of very irregular form. The controlling factors in the localization of the original protore, chiefly pyrite with a little chalcopyrite, and in its subsequent chalcocitic enrichment were zones of fracturing and brecciation. The source of the mineralization, according to Paige, was the quartz monzonite magma. The time of intrusion has been doubtfully identified as late Cretaceous. Enrichment, as at Santa Rita, was probably interrupted for a time by the eruption of Tertiary lavas.

Morenci

At Morenci, Arizona (42, 43), pre-Cambrian crystalline rocks, mainly granite and schist, are unconformably overlain by about 3,000 feet of Paleozoic sediments, comprising Upper Cambrian quartzite, Ordovician limestone, Devonian shale and limestone, and Carboniferous limestone. These, in turn, are unconformably overlain by Cretaceous shale and sandstone, and the entire district was in Tertiary time buried under lava flows.

In late Cretaceous or early Tertiary time the region was elevated, faulted, and invaded by intrusive masses of granitic, quartz monzonitic, and dioritic porphyries. Renewed faulting was followed by ore deposition by solutions that, according to Lindgren, probably emanated from the porphyry magma. Contact-metasomatic deposits, hydrothermal fissure fillings, and disseminated deposits in porphyry are all represented, but deposits of the first two types are mostly exhausted, and the future of the district depends upon the disseminated deposits, estimated to contain about 25,000,000 tons of approximately 2 percent ore. This ore has been formed by supergene chalcocitic enrichment of a protore consisting essentially of pyrite and chalcopyrite, disseminated through the porphyry near and between fissure zones. The district has yielded nearly 2,000,000,000 pounds of copper since 1873.

Bisbee

At Bisbee, Arizona, pre-Cambrian granite and schist are unconformably overlain by Paleozoic sediments ranging in age from Cambrian to Permian. The basal formation, as at Morenci, is a quartzite, but the succeeding beds are mainly limestones. All these rocks were folded and faulted and were intruded by granite porphyry. Subsequently, after long erosion, the older rocks were buried under a thick series of Lower Cretaceous (Comanche) beds. Subsequent faulting, with some folding, was followed by erosion, which reexposed the pre-Cretaceous rocks in part. Some difference of opinion exists as to the age of the granite porphyry intrusion. I believe (44) that it occurred in post-Carboniferous but pre-Cretaceous time. Tenney (45), however, maintains that the granite porphyry is of early Tertiary age.

The copper deposits of Bisbee are predominantly metasomatic replacement deposits in limestone, particularly in the Devonian and Mississippian limestones, though the enclosing calcareous beds suffered generally rather slight contact-metasomatic alteration. The deposits are clearly related to contacts between porphyry and limestone and to zones of fissuring and constitute a cupriferous halo around the principal porphyry stock, on its western and southern sides. The hypogene replacement bodies consist essentially of pyrite and chalcopyrite, with less widely distributed bornite, sphalerite, and galena. Oxidation extends to a maximum depth of 2,200 feet, or 1,200 feet below water level. Bonillas (46) and I believe that this deep oxidation is related to the development of the pre-Cretaceous peneplain, which was later tilted, but Tenney (47), in conformity with his view of Tertiary mineralization, naturally rejects this explanation. Chalcocitic enrichment connected with this deep oxidation played a highly important part in the supergene concentration of the large, high-grade ore bodies, now nearly exhausted, which were the mainstay of Bisbee copper production in the last two decades of the nineteenth century.

The bodies of disseminated ore, which were of later exploitation and which in the Bisbee district are of subordinate importance, occur in the main porphyry stock of Sacramento Hill and in the brecciated and silicified limestones at its margin. They owe their value to supergene chalcocitic enrichment of a low-grade pyrite-chalcopyrite protore.

Miami

In the Miami district, Arizona (48), the fundamental rocks are of pre-Cambrian age and comprise schists and various intrusive rocks ranging from quartz diorite to granite. Unconformably overlying these rocks are sediments which include quartzite and limestone of early Cambrian or Algonkian age, succeeded by quartzite and limestone of Cambrian, Devonian, and Carboniferous time. The Paleozoic and older rocks are cut by various intrusive masses, including granite, quartz monzonite, and diabase, whose age is not definitely determinable. The region was subjected to long erosion, followed, in Tertiary time, by the eruption of thick and extensive flows of dacite. Probably at or near the end of the Tertiary period the rocks of the region were intensely faulted. Vigorous erosion and the deposition of thick detrital valley deposits characterized the Quaternary period.

The disseminated copper deposits occur on the northern margin of a large intrusive mass of sodic granite, partly in porphyritic facies of the granite but mainly in the adjacent schist. The sulphide ore is principally a chalcocitically enriched protore which consisted originally of scattered crystals and small stringers of pyrite and chalcopyrite, with associated quartz, in minutely fractured, sericitized schist and porphyry. At one time rock containing less than about 1.3 percent of copper was classed as protore, but of late years the Miami Copper Co. has mined some chalcopyritic ore containing as little as 0.6 percent of copper. The supergene enrichment of the Miami ore is believed to have been effected mostly in Tertiary time, before eruption of the dacite flows and before the vigorous faulting that followed that eruption. The hypogene mineralization was probably connected genetically with the intrusion of the granite (Schultze granite), which probably occurred in early Tertiary time, although the evidence upon which this conclusion is based is far from conclusive.

The reserves of disseminated copper ore at Miami were originally estimated at 143,282,419 tons, and the production to date has been about 3,000,000,000 pounds of copper.

Ray

In the Ray district, Arizona (48), the general geologic conditions are similar to those at Miami, but the intrusive masses to which the ore deposition was genetically related are quartz monzonite porphyry, of doubtfully early Tertiary age. The ore is almost wholly in schist. The protore is similar mineralogically to that of Miami, although generally of rather lower grade. The total reserves were estimated in 1916 at 93,373,226 tons, with an average tenor of 2.03 percent of copper. The production to date has been about 1,100,000,000 pounds of copper.

Ajo

In the Ajo district, Arizona (49), a superficially small mass of quartz monzonite, probably a lopolith, is intrusive into pre-Cambrian granite and into rhyolitic and andesitic flows of presumably Tertiary age. The ore body, of the disseminated type, is almost entirely in the monzonite. The disseminated sulphides are chiefly chalcopyrite and bornite, with very little pyrite. Probably as a consequence of the scarcity of pyrite, there has been very little supergene enrichment, and the oxidized ore is of nearly the same tenor as the hypogene sulphides. In this respect the Ajo deposit differs notably from the other large disseminated copper deposits of the southwestern United States. The total production has been about 800,000,000 pounds of copper.

Cananea

At Cananea, Sonora, Mexico (50, 51, 52), pre-Cambrian granite is unconformably overlain by Cambrian quartzite and by limestones that are in part as young as Carboniferous. These rocks have been cut by nine kinds of intrusive rocks, ranging from granite to gabbro, and have been in part buried, perhapsat one time completely so, by lava flows and tuffs. All the igneous rocks except the pre-Cambrian granite were believed by Emmons to have been differentiates from a single magma reservoir and have been assumed to be of Tertiary age.

The ore deposits were believed by Emmons to be genetically connected with the Henrietta diorite porphyry, which, as mapped, was regarded by him as actually a complex of intrusives and volcanic rocks (in part tuffs), and to a less extent with the intrusion of the Elisa "quartz porphyry" and of the Cuitaca granodiorite. Later work has tended to show, however, that the Henrietta "diorite" consists mainly of volcanic material (51).

The copper deposits include contact-metasomatic deposits in limestone, nearly vertical pipes or "chimneys" in igneous rocks, and the supergenely enriched chalcocitic deposits of Capote Basin. These last have supplied the greater part of the production but are now practically exhausted.

The Capote Basin deposits occur in much fractured fault blocks, chiefly in Henrietta diorite porphyry and Elisa quartz porphyry. The original disseminated protore, consisting of pyrite, chalcopyrite, and a little sphalerite in much sericitized and silicified porphyry, was, above depths ranging from 300 to 1,000 feet, so greatly enriched by supergene chalcocite as to render it somewhat doubtful whether the resulting ore bodies should be classed as disseminated deposits.

Summary of disseminated deposits

From the foregoing necessarily brief descriptions it appears that the disseminated copper deposits of the southwestern United States and northern Mexico are all within or closely associated with masses of intrusive rock of generally less than batholithic proportions. In composition these rocks range from granite to diorite, but the greater number are quartz monzonite or granodiorite. Commonly it is the porphyritic rather than the granular facies of these rocks which is most closely associated with the ore. The geologic age of these intrusive masses is rarely determinable with certainty. Those of Morenci cut Cretaceous sediments and are older than the Tertiary lavas. The granite porphyry at Bisbee is according to one view post-Carboniferous but pre-Cretaceous; according to another, it is probably Tertiary. In other districts the age is more or less conjectural. Those who favor the view that most of the copper deposits of the Southwest, except those of pre-Cambrian age, originated in a single period of mineralization are naturally predisposed to regard the intrusions as all of early Tertiary age. The protore is generally of rather simple mineralogic character—usually pyrite and chalcopyrite with abundant sericite and secondary quartz. Sphalerite and molybdenite are almost invariably present in small quantity. Bornite is rare, except at Ajo, where, with chalcopyrite, it is abundant. All the deposits, except Ajo, owe their economic importance mainly to supergene chalcocitic enrichment, although locally some of the hypogene material may be classed as ore. At Santa Rita, Tyrone, Morenci, Miami, and Ray evidence has been found to indicate that oxidation and supergene enrichment began before the eruption of the Tertiary lavas.

Other types

To copper deposits of other types in the southwestern region only brief attention can here be given, a few of the more outstanding examples being cited.

Of pre-Cambrian pyritic replacement deposits in schists, Jerome, Arizona (53, 54, 55, 56, 57), affords the most noteworthy illustrations. The basal rocks of the district are crystalline schists, in large part metamorphosed rhyolites and rhyolitic porphyries. These are intruded by a stock of rather basic diorite. These rocks after prolonged erosion were covered by Paleozoic sediments and, after a second epoch of erosion, by Tertiary basaltic flows. Faulting has occurred at various times, and some of the displacements are large. The economically important hypogene ore bodies are confined to the pre-Cambrian rocks.

The district contains two ore bodies of outstanding size and productivity—namely, that of the United Verde mine and that of the United Verde Extension mine. The ore bodies of the United Verde, chiefly chalcopyrite, occur as lenticular masses, in which the copper is distributed through a great pipelike body of quartz, pyrite, sphalerite (marmatite), and very subordinate quantities of other sulphides. This pipe, which lies in an embayment of the diorite, with that rock as the hanging wall, has been mined to a depth of more than 3,000 feet. To a large extent the quartz and sulphides have replaced the previously chloritized schistose rhyolitic rocks into which the diorite is intrusive. The United Verde Extension ore body lies east of the United Verde ore body, on the opposite or hanging-wall side of the great Verde fault. It was not exposed at the surface, being covered by about 850 feet of nearly horizontal Paleozoic beds and Tertiary basalt. The Extension ore body is similar in form and geologic environment to the United Verde ore body but differs from it in two significant respects. It is definitely cut off, at a depth of about 2,000 feet, by the Verde fault, and it was largely converted to supergene chalcocite before the deposition of the Paleozoic beds that now cover it. After a careful study for the United Verde Extension Mining Co., I reached the conclusion that this ore body was originally the upper part of the United Verde ore body; that it was sheared off and relatively downthrown 2,400 feet on the Verde fault in pre-Cambrian time; and that it reached its present relative position by a further throw of 1,600 feet, on the same fault, in Tertiary or Quaternary time.

The total production of the United Verde mine has been nearly 1,900,000,000 pounds of copper, with over 20,000,000 ounces of silver and 400,000 ounces of gold. The United Verde Extension mine has yielded about 600,000,000 pounds of copper, with a proportionate quantity of silver and gold.

Deposits of generally similar type, but smaller and of lower grade than those at Jerome, have been mined in the Bigbug district, a few miles southeast of Prescott, Arizona.

Of metasomatic replacement deposits in limestone, genetically connected with the group of granitic and monzonitic intrusives referred to in the account of the disseminated deposits, those at Bisbee have been most productive, although noteworthy examples are found in the Morenci, Globe, and Christmas districts, Arizona. The Bisbee deposits are described more fully elsewhere in this volume. Deposits in limestone of more decidedly contact-metamorphic type occur at San Pedro and other localities, New Mexico; at Silver Bell, Twin Buttes, and Washington, Arizona; and at Cananea, Mexico.

Deposits essentially of vein type, usually with walls that have been considerably replaced, have also contributed a notable quantity of copper to the production of the southwestern United States. Of this group, the Old Dominion mine, at Globe, and the Magma mine, near Superior, Arizona, stand in the first rank. The mineralization that produced these ore bodies is generally ascribed to the same magmatic source as that to which the disseminated ore deposits of the region are due.

Brief mention must be accorded, also, to the interesting deposits of columnar or pipelike form exemplified by the Pilares deposit, near Nacozari, and the

Duluth-Cananea and Colorada deposits, near Cananea, all in Mexico. The Pilares deposit (58, 59, 60) is essentially a nearly vertical, somewhat flattened cylinder of chalcopyrite ore, in rocks described as latite breccia, andesite breccia, and monzonite. The plug is composed of the same rocks as those which enclose it but shows clear evidence of subsidence. The occurrence of the ore around the margin of the plug and as more or less isolated bodies within it is clearly conditioned by fracturing and faulting. Various hypotheses of origin have been advanced, but these are largely conjectural.

The latest deposit to be discovered at Cananea, the Colorada, found by drilling in 1926, is a remarkable mass of bornite, chalcopyrite, chalcocite, and quartz in the general form of an inverted hollow cone which terminates at a depth of about 1,300 feet. The mass occurs at the contact of a body of Elisa quartz porphyry with Henrietta diorite porphyry.

The unique deposits near Santa Rosalia, Baja California (61), occur as four main mineralized argillaceous beds, interstratified with tuffs and conglomerates of Pliocene age. The most abundant sulphide is chalcocite, associated with covellite, bornite, chalcopyrite, and a very little pyrite. In the higher beds the sulphides have been largely oxidized, and nearly every known oxidized compound of copper is represented, as well as native copper and some rare lead-copper minerals such as boleite and cumengite.

According to Touwaide, the copper was extracted from the pyroxenes of the tuffs by connate waters and was precipitated in the clayey layers, chiefly as chalcocite and native copper. The deposits accordingly were formed long after the intrusion of the Coast Range batholith and have no direct genetic connection with that event.

It is worthy of note, although the deposit has not been economically developed, that native copper and chalcocite are widely distributed through a thick series of basaltic or andesitic amygdaloidal lava flows in the Comobabi Mountains of southwestern Arizona. The copper minerals occur chiefly in the amygdules, associated with quartz and epidote. The lavas have been tilted and truncated by erosion and are probably pre-Tertiary. They are cut by felsitic dikes, which are also mineralized to some extent with copper.

Copper deposits of the Pacific coast north of Mexico

California

In California the outstanding geologic feature to which most of the copper deposits are clearly related was the intrusion of the Sierra Nevada batholith, consisting mainly of granodiorite, in early Cretaceous time. This batholith is probably connected, under the lavas of the Cascade Range of Oregon and Washington, with the Coast Range batholith of British Columbia and Alaska, which is structurally more complex than the Sierra Nevada mass and represents successive intrusions that apparently began in Jurassic time, or slightly earlier than in California. Most of the metalliferous deposits of the Pacific coast, except those of mercury, appear to be genetically connected with the intrusion of the various plutonic rocks, ranging from granite to gabbro, which make up the Sierra

Nevada and Coast Range batholith and, consequently, to be of late Jurassic or early Cretaceous age. They occur in belts of metamorphic rocks adjacent to the intrusive mass, in roof pendants, and, to a much less extent, in the marginal portions of the batholith itself (62).

At Copperopolis, Calaveras County, California (63), copper has been produced from lenticular bodies of chalcopyrite and pyrite in greenstone schist (meta-andesite) of probable Jurassic age. The deposition of the ore was supposedly a consequence of the intrusion of the Sierra Nevada batholith. According to Reid, the copper deposition was slightly earlier than the formation of the gold quartz veins of the adjacent Mother Lode belt.

Smaller deposits, generally similar to those at Copperopolis, occur elsewhere along the western base of the Sierra Nevada and also in British Columbia.

The Engels copper deposits, in Plumas County, California (64), are high-temperature deposits consisting chiefly of bornite, chalcopyrite, magnetite, and ilmenite in pneumatolytically altered gabbro, quartz diorite, andesite, and other rocks. They occur at and near the contacts of roof pendants in the gabbro and younger quartz diorite. The region was apparently an area of magmatic differentiation, and it is not clear which of the differentiated submagmas was the cause of the mineralization. In a broad sense, the ores are genetically related to the intrusion of the Sierra Nevada batholith.

In Shasta County, California (65, 66), large bodies of pyrite, with some chalcopyrite, occur as replacement masses in rhyolite porphyry. They have yielded much copper since their development in 1895 but are now largely exhausted or of too low grade to be profitable. The porphyry is intrusive into closely folded slates and schists of Devonian and Carboniferous age, and the intrusion was slightly earlier than that of an associated quartz diorite which is probably equivalent to the granodiorite of the Sierra Nevada batholith. Graton regards the ore as having been deposited by replacement in zones of shearing and brecciation by solutions emanating from the magma, which solidified as rhyolite (alaskite) porphyry. This is equivalent to relating their deposition, in a broad sense, with the intrusion of the Sierra Nevada batholith.

British Columbia

The copper deposits worked by the Britannia mines, east of Howe Sound and north of Vancouver, British Columbia (67, 68), are among the most productive in Canada, with an annual production of about 30,000,000 pounds of copper and a total since 1904 of about 250,000,000 pounds. The ore bodies, consisting chiefly of pyrite, chalcopyrite, and quartz, locally with sphalerite, barite, anhydrite, and rare galena, occur as large replacement veins in a great shear zone. The rock replaced is a greenish mottled schist which has been formed by the shearing and metamorphism of porphyry sills composed originally of dacite and quartz latite. The entire mass of metamorphic rocks, of which the sills are a part and which consists largely of originally volcanic material of probable Mesozoic age, has been irregularly invaded, supposedly in Jurassic time, by the granodioritic intrusives of the Coast Range batholith. This mass is probably a great roof pendant in the batholith, from which, it is believed, were derived the hydrothermal solutions that deposited the ores.

In the same general region copper deposits associated with hematite, magnetite, and molybdenite occur within the batholith itself and have been interpreted as having been deposited at higher temperature than the ores in the Britannia shear zone (68, p. 119).

The Tyee deposit, at Mount Sicker, southern Vancouver Island, formerly productive, resembles in some respects the Britannia ore bodies.

The ores of the Rossland district, British Columbia (69), although most valuable for their gold, are generally so cupriferous as to deserve mention among the copper deposits. The ores most characteristic of the district consist mainly of pyrrhotite and chalcopyrite with a subordinate gangue of altered country rock. They occur along zones of fissuring and shearing and to a large extent represent replacement of the rock adjacent to or between the fissures. The geologic relations are complex, but the ore bodies occur chiefly in "augite porphyrite" of supposed Carboniferous age, which has been extensively invaded by monzonitic facies of the Coast Range batholith, the intrusion of which is tentatively dated as late Jurassic. The mineralization was probably a late manifestation of the batholithic intrusion.

The Boundary district, adjacent to Phoenix, British Columbia, which 20 years ago was the leading producer of copper in Canada, has been described by Le Roy (70). The rocks comprise the Knob Hill group, consisting of clastic rocks of igneous origin, porphyries, and subordinate sedimentary rocks, overlain by the Atwood series of metamorphosed limestones and argillites, of supposed Carboniferous age. These have all been tentatively classed as Paleozoic. The Tertiary is represented by the Kettle River formation and the Midway volcanic group.

The ore bodies, consisting essentially of disseminated chalcopyrite, pyrite, and hematite, associated with magnetite, epidote, garnet, quartz, calcite, and chlorite, occur as metasomatic replacement deposits in the Brooklyn limestone of the Atwood series. The mineralogy of the ores indicates contact-metamorphic action, but they are not obviously related to any visible intrusive mass. They are supposed by LeRoy, however, to represent emanations from the magma of the Coast Range batholith.

At Allenby (Copper) Mountain, about 13 miles south of Princeton, in the Similkameen district, British Columbia, a stock of monzonite is intrusive into Paleozoic sediments, and both rocks are cut by innumerable dikes of various kinds. Copper ores occur at the contact between the monzonite and sediments and as lenses in fracture zones. The ores in the fracture zones, which apparently are the more valuable, contain pyrite, chalcopyrite, arsenopyrite, and magnetite. They are reported to average between 1.5 and 2.0 percent of copper, with a little gold and silver (11, p. 170).

At Anyox, on Portland Canal, British Columbia (11, p. 172) deposits which for many years have yielded about 30,000,000 pounds of copper annually occur in a belt of schists and metamorphosed sediments enclosed in the granodioritic rocks of the Coast Range batholith. The ore bodies are large and consist chiefly of pyrite, pyrrhotite, chalcopyrite, sphalerite, magnetite, and arsenopyrite. They appear to resemble in many respects the deposits of northern Manitoba.

Alaska

The remarkable copper deposits near Kennecott, Alaska, have been well described by Bateman and McLaughlin (71). The principal ore bodies are fissure veins, massive replacement bodies, and stockworks, in the thick Upper Triassic Chitistone limestone, which overlies the altered basaltic flows of the Triassic Nikolai greenstone. The most abundant ore mineral is chalcocite, which forms over 95 percent of the ore. Associated with the chalcocite are covellite, enargite, bornite, chalcopyrite, luzonite, tennantite, pyrite, sphalerite, and galena, listed in the order of decreasing abundance.

The fissures are believed by Bateman and McLaughlin to be the result of tension in the limestone produced by synclinal folding. The copper is regarded as having been derived from the underlying greenstones, which themselves contain small and scattered deposits of copper ore. The transporting agent is believed to have been meteoric water which was heated in its passage through the greenstones, possibly as a result of heat from a magmatic source. The heated water gathered the copper from the greenstones and carried it upward to the places favorable for deposition, in the limestone. The chalcocite and associated sulphides are considered to be hypogene.

The copper deposits of Copper Mountain and the Kasaan Peninsula, Prince of Wales Island, Alaska, described by Wright (72), are principally pyrometasomatic contact deposits which are obviously related in genesis to the intrusion of the Coast Range batholith. They occur in limestone, chiefly of Devonian age.

Classification of the deposits

From the facts presented in the foregoing review it is clear that copper deposition in North America was not confined to any particular geologic age or ages, although the exact period within which many of the deposits were formed remains in doubt. That the important copper deposits of Jerome, Arizona, are pre-Cambrian is highly probable, and that they are pre-Devonian is certain. The Lake Superior ores are definitely pre-Cambrian, and it is probable, though not certain, that the copper ores of the Canadian Shield are also older than Cambrian. Here probably also belong the copper deposits of Encampment, Wyoming.

The Ducktown deposits occur in Lower Cambrian rocks but are regarded by Emmons and Laney as being of late Paleozoic age, that being the time of the youngest granitic intrusives of the region. The metamorphosed deposits of Maine and New Hampshire, according to Emmons, are post-Cambrian and pre-Silurian. The Virgilina deposits are considered by Laney to be probably late Paleozoic, for the same reason as the Ducktown deposits. Deposits of the New Jersey type, including that of Bristol, are obviously Triassic or younger. The Butte veins are probably of early to middle Tertiary age.

The Bingham Canyon ores are post-Carboniferous and may be Tertiary. At Ely, Nevada, the mineralization was post-Carboniferous and, according to Spencer, probably late Jurassic. At Santa Rita the ores are post-Cretaceous and rather probably Tertiary. At Tyrone a late Cretaceous age is doubtfully assigned to the ores by Paige. At Morenci Lindgren showed that the ores are younger than certain Cretaceous beds and older than supposedly Tertiary lavas. He regarded them, therefore, as late Cretaceous or early Tertiary. At Globe, Miami, Ray, Superior, and Ajo, the age relations of the ore are uncertain. Such general evidence as is available is indicative of a Tertiary age for these deposits. At Bisbee I considered the ores to be post-Carboniferous and pre-Comanche, but others have since suggested a Tertiary age for these deposits. The ores of Cananea are post-Carboniferous and have been assigned, without entirely satisfactory evidence, to the Tertiary. Those of Pilares, are presumably, though not demonstrably, also Tertiary. The Boleo deposits, in Baja California, according to Touwaide, are Pliocene. In California, British Columbia, and Alaska the copper deposits, inasmuch as most of them are apparently consequences of the intrusion of the Pacific coast batholith, are commonly regarded as of late Jurassic or early Cretaceous age. The exceptional deposits at Kennecott are definitely later than Upper Triassic and may be of the same general age as those more closely related to the batholith.

Although the deposition of copper ores was thus not restricted to any one geologic period, even in a single region, in general the process has closely followed or accompanied the major orogenic and igneous manifestations in the various provinces. Thus, in the Appalachian region the more important deposits are probably of late Paleozoic age, although some are recorded as pre-Silurian. In the Canadian Shield, which has suffered little deformation since the beginning of the Cambrian, the copper ores are mainly pre-Cambrian. In the Rocky Mountain region such copper deposits as occur appear to range in age from pre-Cambrian to Tertiary. The outstanding deposits at Butte may possibly be related to the Laramide revolution, although they appear to be somewhat later. Those of the Basin and Range province, in the southwestern United States, are in part pre-Cambrian, in part possibly Mesozoic, but the greater number are connected in origin with monzonitic intrusions referable, with various degrees of probability, to early Tertiary time, when marine sedimentation was ended by uplift. The deposits of the Pacific coast, from California to Alaska, are genetically connected, for the most part, with the batholithic intrusions of late Jurassic or early Cretaceous time. The Boleo deposits, of supposed Pliocene age, stand by themselves. Of possible late origin, also, are some of the deposits in the "red beds" of younger Paleozoic or older Mesozoic age in the Colorado Plateau region and in New Mexico.

With respect to general form, it appears that the copper deposits of the Canadian Shield and the pre-Cambrian deposits elsewhere are predominantly lenticular replacement masses in schistose rocks, related to zones of shearing. Deposits of the disseminated sulphide type are practically confined to the relatively arid Basin and Range province, where conditions of climate and underground-water table have been favorable to the process of supergene enrichment, to which most of them owe their economic value. In this region also occur most of the great metasomatic replacement deposits in limestone, which are due to the concurrent circumstances that the Paleozoic beds are largely calcareous and have been invaded at many localities by monzonitic masses. Typical vein deposits, except at Butte, have not contributed largely to the total output of copper in North America, although in Arizona some individual mines, such as the Old Dominion and Magma, have been operated with great success on deposits of this form.

As regards mineralogic character, the native-copper ores of the Lake Superior region stand practically alone, although there are some points of similarity between them and the economically unimportant ores of the Catoctin type in the Appalachians, the undeveloped deposits of the Comobabi Mountains, Arizona, and those of the Coppermine River, District of Mackenzie, Canada.

In the pre-Cambrian deposits and those of Paleozoic age the principal hypogene copper mineral is chalcopyrite, often found associated with pyrrhotite, pyrite, and sphalerite and, less commonly, with magnetite and marcasite.

The mineralogic combination of pyrite, enargite, bornite, and hypogene chalcocite found in the Butte veins is probably unique among the large copper deposits of North America. At Butte these minerals may be associated also with chalcopyrite, tetrahedrite, tennantite, and covellite.

The disseminated copper deposits of the southwestern United States are generally simple mineralogically. The common sulphides are pyrite and chalcopyrite. Molybdenite, in relatively small quantity, is almost invariably present. Sphalerite may be a minor constituent of the protore but is never conspicuous, and galena is rare. Bornite is not common, except at Ajo and Bisbee, although it occurs in the Bingham Canyon ore. Chalcocite, the principal mineral in the zone of enrichment, is invariably supergene. In the metasomatic replacement deposits in limestone, in the same region, the common hypogene ore is an aggregate of pyrite and chalcopyrite, with gradations into practically pure chalcopyrite. Bornite may be an abundant constituent of some ore bodies, as at Bisbee, and sphalerite and galena may be locally present. Tennantite is rare but has been noted at Bisbee.

The association of hypogene chalcocite and bornite has been noted by Laney in the Virgilina district and by Bateman at the Bristol mine, on the Atlantic seaboard. A similar association on a larger scale is shown in the vein of the Magma mine, in the Superior district, Arizona. Here the hypogene ore consists of chalcopyrite, bornite, and chalcocite, with smaller quantities of tennantite, sphalerite, and galena. A very little enargite serves to link the Magma ore mineralogically with the Butte veins.

Genetically most of the economically important copper deposits of North America are related to intrusive igneous rocks, although the relation is not invariably as definite as might be desired for a positive statement. For example, it is not certain whether the copper deposits at Jerome, Arizona, are consequent upon the intrusion of the regionally extensive Bradshaw granite or that of a local mass of basic diorite. Again, the copper of the native copper deposits of the Lake Superior region is thought by Butler and Burbank to have originated in the magma of the Duluth gabbro, but proof of this relationship is not available. On the other hand, the connection between the disseminated copper deposits of the southwestern United States and the intrusion of monzonitic or granitic masses is beyond question. The same may be said of the many deposits that occur on the margins of the granodioritic Pacific coast batholith.

Among the large deposits that cannot be closely linked to igneous intrusion may be mentioned the Kennecott deposit in Alaska and the Boleo deposit in Baja California. Here also belong the chalcocite deposits in the "red beds" and other sedimentary rocks in the southwestern United States. Copper is readily transportable as sulphate in surface waters and may be deposited not only as chrysocolla and carbonates but also, under some circumstances, as sulphides, particularly as chalcocite. Such hypogene deposits, however, are of minor economic importance.

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Copper in Canada[1]

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Introduction

From 1928 to 1931 Canada ranked fourth among the copper-producing countries of the world, being surpassed only by the United States, Chile, and the Congo. In 1931 about 23 percent of the Canadian output was derived from the low-grade copper ores of British Columbia, which require concentration before smelting, about 15 percent from the copper-zinc-gold ores of northern Manitoba, about 38 percent from the nickel-copper ores of the Sudbury region, Ontario, and 24 percent from the copper-gold-zinc ores of Rouyn and adjoining areas of northwestern Quebec. There was also a little copper concentrate from the treatment of cupriferous pyrite from the Eustis mine, in southeastern Quebec, shipped to United States smelters; formerly a considerable production of copper was maintained from this region. In 1932 there was a total decrease, as compared with the output for 1931, of 15 percent in quantity and 37 percent in value. Manitoba showed an increase of 15 percent, Quebec's production remained about the same, but British Columbia and Ontario both showed a marked decrease. The following table indicates the changes in the relative importance of the several producing regions from 1886 onward.

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Copper produced in principal Canadian regions in certain years, in pounds

Year	Yukon	British Columbia	Ontario	Manitoba	Quebec
1886	....	....	165,000	....	3,340,000
1894	....	324,680	5,207,679	....	2,176,430
1907	511,838	40,832,720	14,104,337	....	1,517,990
1912	1,772,550	50,526,656	22,250,001	....	3,282,210
1917	2,460,079	57,730,959	42,867,774	1,116,000	5,015,560
1918	619,878	62,865,681	47,074,475	2,339,751	5,869,649
1922	....	32,101,357	10,778,461	....	....
1924	....	65,451,246	37,113,193	....	1,893,008
1926	....	89,108,017	41,312,867	....	2,674,058
1928	....	102,283,210	66,607,510	....	33,697,949
1930	42,628	93,318,885	127,718,871	2,087,609	80,310,363
1931	....	65,223,348	112,882,625	45,821,432	68,376,985
1932	....	50,580,104	77,055,413	52,706,294	67,336,692

In the table below is listed the total Canadian production from 1886 to 1932, including copper in ores and concentrates exported, in blister copper made, in matte exported, and in copper sulphate made.

Total production of copper from Canadian ores, 1886–1932

Year	Quantity (pounds)	Value		Year	Quantity (pounds)	Value	
		Total	Per pound (cents)			Total	Per pound (cents)
1886	3,505,000	$385,550	11.00	1910	55,692,369	$7,094,094	12.738
1887	3,260,424	366,798	11.25	1911	55,648,011	6,886,998	12.376
1888	5,562,864	927,107	16.66	1912	77,832,137	12,718,548	16.341
1889	6,809,752	936,341	13.75	1913	76,976,925	11,753,606	15.269
1890	6,013,671	947,153	15.75	1914	75,735,960	10,301,606	13.602
1891	9,529,401	1,226,703	12.87	1915	100,785,150	17,410,635	17.275
1892	7,087,275	818,580	11.55	1916	117,150,028	31,867,150	27.202
1893	8,109,856	871,809	10.75	1917	109,227,332	29,687,989	27.180
1894	7,708,789	736,960	9.56	1918	118,769,434	29,250,536	24.628
1895	7,771,639	836,228	10.76	1919	75,053,581	14,028,265	18.691
1896	9,393,012	1,021,960	10.88	1920	81,600,691	14,244,217	17.456
1897	13,300,802	1,501,660	11.29	1921	47,620,820	5,953,555	12.502
1898	17,747,136	2,134,980	12.03	1922	42,879,818	5,738,177	13.382
1899	15,078,475	2,655,319	17.61	1923	86,881,537	12,529,186	14.421
1900	18,937,138	3,065,922	16.19	1924	104,457,447	13,604,538	13.024
1901	37,827,019	6,096,581	16.117	1925	111,450,518	15,649,882	14.042
1902	38,804,259	4,511,383	11.626	1926	133,094,942	17,490,300	13.795
1903	42,684,454	5,649,487	13.235	1927	140,147,440	17,195,487	12.920
1904	41,383,722	5,306,635	12.823	1928	202,696,046	28,598,249	14.570
1905	48,092,753	7,497,660	15.590	1929	248,120,760	43,415,251	18.102
1906	55,609,888	10,720,474	19.278	1930	303,478,356	37,948,359	12.982
1907	56,979,205	11,398,120	20.004	1931	293,476,206	24,185,119	8.116
1908	63,702,873	8,413,876	13.208	1932	247,678,503	15,294,022	5.555
1909	52,493,863	6,814,754	12.982				

Refined copper was first produced in Canada in commercial quantity in 1916 at the Trail refinery of the Consolidated Mining & Smelting Co. The British American Nickel Corporation, which first produced refined copper at the Deschenes refinery, near Aylmer, Quebec, in 1920, went into liquidation during July, 1924.

The production of electrolytic copper in the form of wire bars, small ingots, ingot bars, cathodes, and "V.C." cakes began in 1930 at the new copper refinery in Copper Cliff, Ontario. This refinery treats blister copper made by the International Nickel Co. of Canada and the Granby smelter at Anyox, British Columbia.

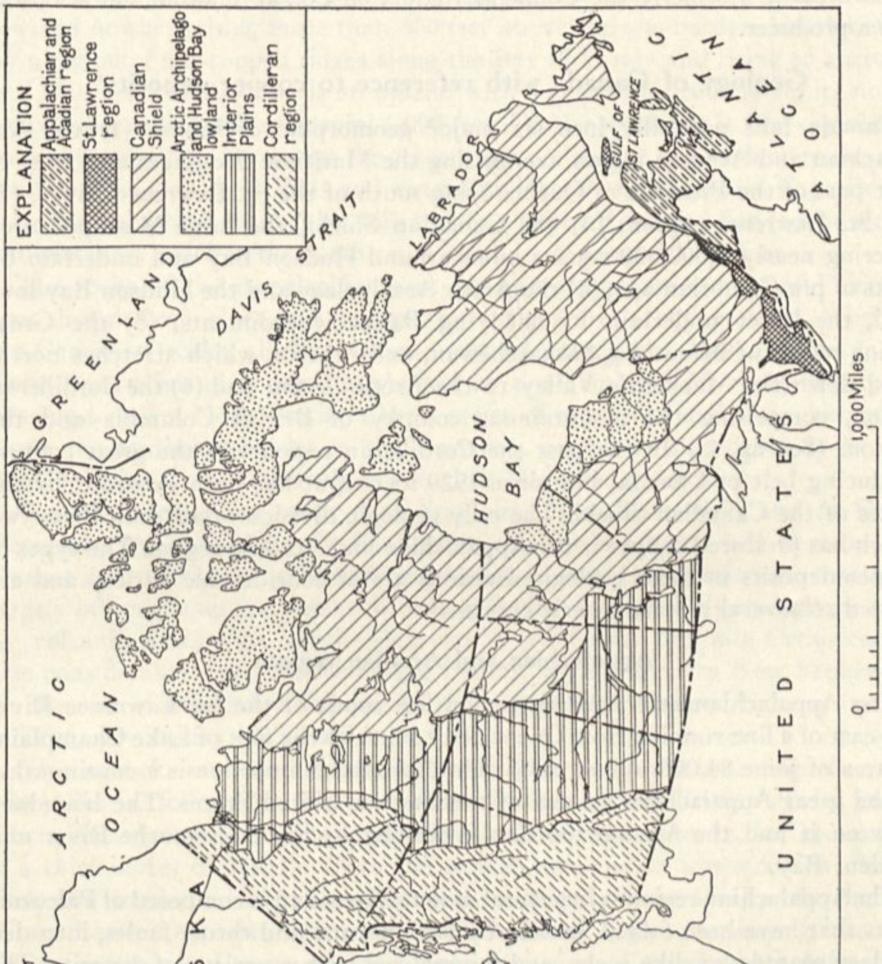


FIGURE 2.—Geomorphic divisions of Canada.

The refinery of the Canadian Copper Refiners, Ltd., a subsidiary of Noranda Mines, Ltd., at Montreal East, was completed in January, 1931, and began turning out wire bars in April, 1931. It has a capacity of 75,000 tons a year and handles the blister copper of Noranda Mines, Ltd., of Quebec, and of the Hudson Bay Mining & Smelting Co.'s property at Flin Flon, northern Manitoba. The

Canada Wire & Cable Co. completed its fabricating plant adjacent to this refinery and began operations in May, 1931.

The Consolidated Mining & Smelting Co., Ltd., of Trail, British Columbia, is now the only producer of copper sulphate in Canada and uses the output in its own plant. Formerly the Coniagas Reduction Co., at Thorold, Ontario, was also a producer.

Geology of Canada with reference to copper deposits

Canada falls naturally into six major geomorphic divisions—(1) the Appalachian and Acadian region, comprising the Maritime Provinces and most of that part of the Province of Quebec lying south of the St. Lawrence River; (2) the St. Lawrence region; (3) the Canadian Shield, the large V-shaped area covering nearly 2,000,000 square miles around Hudson Bay and underlain by rocks of pre-Cambrian age; (4) the Arctic Archipelago and the Hudson Bay lowland, the latter underlain by flat-lying Paleozoic sediments; (5) the Great Plains region of Manitoba, Saskatchewan, and Alberta, which stretches northward down the Mackenzie Valley to the Arctic Ocean; and (6) the Cordilleran region, comprising the mountainous country of British Columbia and the Yukon. (See fig. 2.) In the past the Cordilleran region was the great copper-producing belt of Canada, but since 1929 its output has been exceeded by the mines of the Canadian Shield. The only geologic division other than these two which has produced copper is the Appalachian and Acadian region. The types of copper deposits in these geologic divisions are of considerable variety and are related to several metallogenetic epochs.

Appalachian and Acadian region

The Appalachian and Acadian region lies south of the St. Lawrence River and east of a line running from Quebec city south to the foot of Lake Champlain, an area of some 84,000 square miles. The Appalachian portion is a continuation of the great Appalachian system of the eastern United States. The boundary between it and the Acadian portion is formed by the Restigouche River and Chaleur Bay.

The Appalachian region is in general mountainous and is composed of Paleozoic rocks that have been folded, broken by both normal and thrust faults, intruded by deep-seated and dike rocks, and mineralized with a variety of deposits. The general structural trend is northeast. South of New York the mountain system comprises two parallel ranges, the Allegheny and the Appalachian, but in northern New York, New England, and Canada the system is less regular. The Green Mountains and White Mountains of New England and the Notre Dame Mountains of Quebec trend in general northeast and form three roughly parallel ridges with isolated hills as much as 3,100 feet high, separated from one another by deep valleys. In the region of Quebec city the country is lower, but in Gaspe Peninsula it again rises, and a belt of flat-topped country known as the Shickshock Mountains, which reach altitudes of 3,000 to 4,200 feet, extends down the middle of the peninsula.

The Acadian region is also one of ridges, plateaus, and valleys. The northwestern part of New Brunswick is a plateau deeply entrenched by the valley of the St. John River. The central part of this Province is more rugged, with ridges and hills rising to altitudes of over 2,000 feet. The southeastern part, except a belt along the Bay of Fundy, and all of Prince Edward Island form a lowland nowhere rising more than 600 feet above the sea, bordered in the south by a region of flat-topped ridges along the Bay of Fundy and rising to altitudes of 1,000 feet. Nova Scotia is an upland with a general altitude along its northeastward-trending axis of around 1,000 feet. On the southeast it drops gradually to the ocean; on the northwest the descent is more abrupt to a lowland region surrounding the Cobequid Hills and extending into New Brunswick. Cape Breton Island is an upland divided by valleys into a series of isolated flat-topped ridges and plateaus, which in the north reach altitudes of around 1,500 feet.

The rocks of the Appalachian and Acadian region are mostly of Paleozoic age, though both older and younger formations are locally present. A belt of pre-Cambrian rocks, chiefly volcanic, extends along the Bay of Fundy, and Cape Breton Island is partly underlain by pre-Cambrian (?) rocks. The gold-bearing series of Nova Scotia, a thick series of quartzites and slates extending along the southeast border of the Province, is usually considered to be late pre-Cambrian. It is extensively intruded by Devonian granite.

Cambrian sediments occur near St. John, New Brunswick, and in Gaspe Peninsula, Quebec. Along the St. Lawrence River is a broad belt of rocks, the Quebec group, believed to be of Cambrian and Lower Ordovician age, consisting largely of limestones and shales. In Gaspe Peninsula these beds are accompanied by volcanic rocks with interbedded clastic sediments. The late Ordovician is also considerably developed in Gaspe Peninsula and northern New Brunswick. At the end of the Ordovician period the region was deformed by a mountain-building revolution, the Taconic.

Silurian rocks are found in Gaspe, New Brunswick, southeastern Quebec, and Nova Scotia, followed in Gaspe and northwestern New Brunswick by Lower Devonian limestones and shales accompanied by volcanic rocks. In Gaspe there is a thick series of Middle Devonian sandstones, and in western New Brunswick and southern Gaspe late Devonian sediments occur locally. At the end of the Lower Devonian epoch mountain building began, continuing into late Devonian time and accompanied by the intrusion of granite batholiths. This period of folding and intrusion was the chief metallogenetic epoch of the Appalachian and Acadian region, and all the copper deposits of the region except a few in Carboniferous rocks are related to it. Granites of this age occur in southeastern Quebec, Gaspe Peninsula, New Brunswick, and Nova Scotia. Copper deposits are numerous and widely scattered throughout the region, but important production has been limited to the pyritic ores in southeastern Quebec, referred to later. In southern New Brunswick copper-bearing minerals, chiefly chalcopyrite but also locally bornite, occur at many localities in schistose and igneous rocks.

Carboniferous strata occupy the great lowland area of eastern New Brunswick, also northern Nova Scotia and Prince Edward Island. Chalcocite, malachite, and other copper minerals are disseminated in small quantities through certain sandstones of Pennsylvanian age southeast of Moncton, in the vicinity of Dorchester, and also near New Horton, as well as in the Carboniferous near Northumberland Strait, Nova Scotia. The chalcocite is associated with plant remains. Probably the mineralization was caused by meteoric waters that had leached copper from small quantities of chalcopyrite and other copper minerals in the sediments, the copper being subsequently deposited by the reducing action of carbonaceous material below the zone of oxidation. The copper minerals were originally derived from widely scattered small deposits of copper sulphides in the pre-Carboniferous complex that supplied the material for the Carboniferous sediments.

The youngest rocks of the Appalachian and Acadian region are Triassic. A few patches of red clastic sediments occur on the New Brunswick side of the Bay of Fundy, and there is a narrow strip of Triassic sandstone and volcanic rocks on the Nova Scotia side. At Cap d'Or, Nova Scotia, native copper occurs in small amounts in veins and along joints in the diabase.

St. Lawrence region

The St. Lawrence region is a lowland extending from the city of Quebec westward to Lake Huron. It is underlain by little-disturbed sediments, ranging in age from Cambrian to Devonian. The only igneous rocks are the intrusive masses forming the Monteregian Hills. The region has no deposits of copper.

Canadian Shield

The Canadian Shield, composed of pre-Cambrian rocks, has an area of 1,825,000 square miles, or more than half of the whole of Canada. It is a plateau-like region only locally rising more than 1,500 or 2,000 feet above the sea except in Labrador Peninsula, where altitudes of over 5,000 feet are reached. The most characteristic feature of the Shield is its low relief. An observer standing anywhere on an elevation sees an even sky line in every direction. Throughout most of the region the hills and ridges rise no more than 100 or 200 feet above the adjacent lakes and valleys. In places, however, as locally along the southern margins of the Shield and in northeastern Quebec along the Labrador border, the relief is considerably greater. Despite the general low relief, the topography is very irregular in detail, consisting of low, hummocky hills and ridges separated by depressions that are commonly occupied by lakes or muskegs. Lakes of all sizes and shapes and with numerous islands dot practically the entire region, in places giving the appearance of a drowned area with only the ridges projecting. Many of the rivers are a mere succession of lake expansions connected by stretches in which rapids and waterfalls are numerous.

The rocks are mainly of pre-Cambrian age and form a continental mass which in pre-Cambrian time extended out in all directions beyond the present limits of the Shield. During the Paleozoic and Mesozoic eras it was at least partly flooded many times by seas that advanced over it and later retreated. The sediments that accumulated in these seas were largely swept away by later erosion.

Since the beginning of the Cambrian the Shield has been a stable mass whose only movements were epeirogenic. The pre-Cambrian history, however, was complicated, including periods of volcanism, sedimentation, folding, mountain building, and igneous intrusion, besides long periods of quiescence and dominant erosion.

Pre-Cambrian time can conveniently be divided into two major divisions, which may be termed "early pre-Cambrian" and "late pre-Cambrian." The early pre-Cambrian in turn falls into two divisions, in the earlier of which volcanism took place on a tremendous scale and lavas, usually referred to as "Keewatin," accumulated over wide areas in thicknesses measured in thousands of feet. With the lavas are locally associated sediments, in many places altered to mica schists and gneisses. In eastern Ontario and southwestern Quebec a thick series of limestone, quartzite, and sedimentary gneiss known as the "Grenville series" is also usually considered as having been deposited in this first part of the early pre-Cambrian. Following this were widespread but gentle folding movements accompanied by some granitic intrusions. During the second part of the early pre-Cambrian a series of clastic sediments accumulated, known in different districts under various names, such as "Timiskaming," "Windegokan," and "Pontiac." This period of sedimentation was succeeded by a mountain-building revolution accompanied by widespread granite intrusions, forming the Algoman batholiths. The Algoman was one of the great metallogenetic epochs of the pre-Cambrian, in which the copper-zinc deposits of Noranda, Amulet, Waite-Ackerman-Montgomery, and others of northwestern Quebec and the Flin Flon, Mandy, and Sherritt-Gordon of northern Manitoba were formed. Other less important Algoman deposits are (1) near Big Duck Lake, 14 miles north of Schreiber, on the north shore of Lake Superior, where a vein is composed of quartz carrying pyrite, chalcopyrite, copper carbonates, and a little molybdenite in hornblende schist; (2) west of Lake Superior, at Round Lake, a few miles north of Shebandowan, where bodies of copper ore consisting of chalcopyrite, pyrite, and country rock occur in silicified schist; (3) farther west, near Mine Center, where there are several chalcopyrite, pyrite, and pyrrhotite deposits along narrow zones in schists.

The early pre-Cambrian was followed by a long period of quiescence in which erosion reduced the region to low relief.

The late pre-Cambrian included the long period during which the Huronian and Keweenawan rocks accumulated on this eroded complex. North of Lake Huron the Huronian strata consist of an older (Bruce) series, made up of 10,000 to 15,000 feet of quartzites with a limestone member and in places a basal conglomerate, and a younger (Cobalt) series of conglomerate, graywacke-conglomerate, slate, and quartzite, in places 10,000 feet thick. Along the north shore of Lake Superior is a series (Animikie) of nearly horizontal conglomerate, iron formation, and dark slates, classed by some workers as Upper Huronian and by others as Keweenawan. East of Port Arthur the Animikie is overlain, in places with a slight unconformity, by Keweenawan conglomerate, sandstone and shale, limy beds, and tuffs, with acidic and basic lava flows on top.

The Keweenawan was an important metallogenetic epoch. Volcanic activity and igneous intrusion took place on a vast scale. On the south shore of Lake Superior lavas accumulated to a thickness of over 22,000 feet in the lower part of the series. Notable copper deposits are found in this series. Similar deposits occur in northern Canada on the Coppermine River (see pl. 2), and on the islands of Bathurst Inlet. Dikes of this age are common throughout most of the Canadian Shield, and thick sills of quartz diabase, also probably of this age, invade the Huronian rocks. In the Sudbury region is a norite interformational intrusive of probable Keweenawan age between the base of a series of late pre-Cambrian rocks and the underlying complex of older rocks. The great nickel-copper deposits of this region are differentiates of this intrusive mass. Deep-seated intrusives of this age also invade the Huronian and Keweenawan rocks. South of Lake Superior the Duluth gabbro forms a lopolithic mass 100 miles in diameter. North of Lake Huron the Huronian sediments and diabase sills are folded and faulted and intruded by the Killarney granite, of Keweenawan age, to which the copper deposits of that area are probably related. They are veins traversing Huronian sediments and the sill-like bodies of diabase that intrude these strata. The veins are composed of quartz and chalcopyrite with minor amounts of calcite and barite and locally pyrite, chalcocite, and sphalerite. The largest ore bodies of this area are those at Bruce Mines.

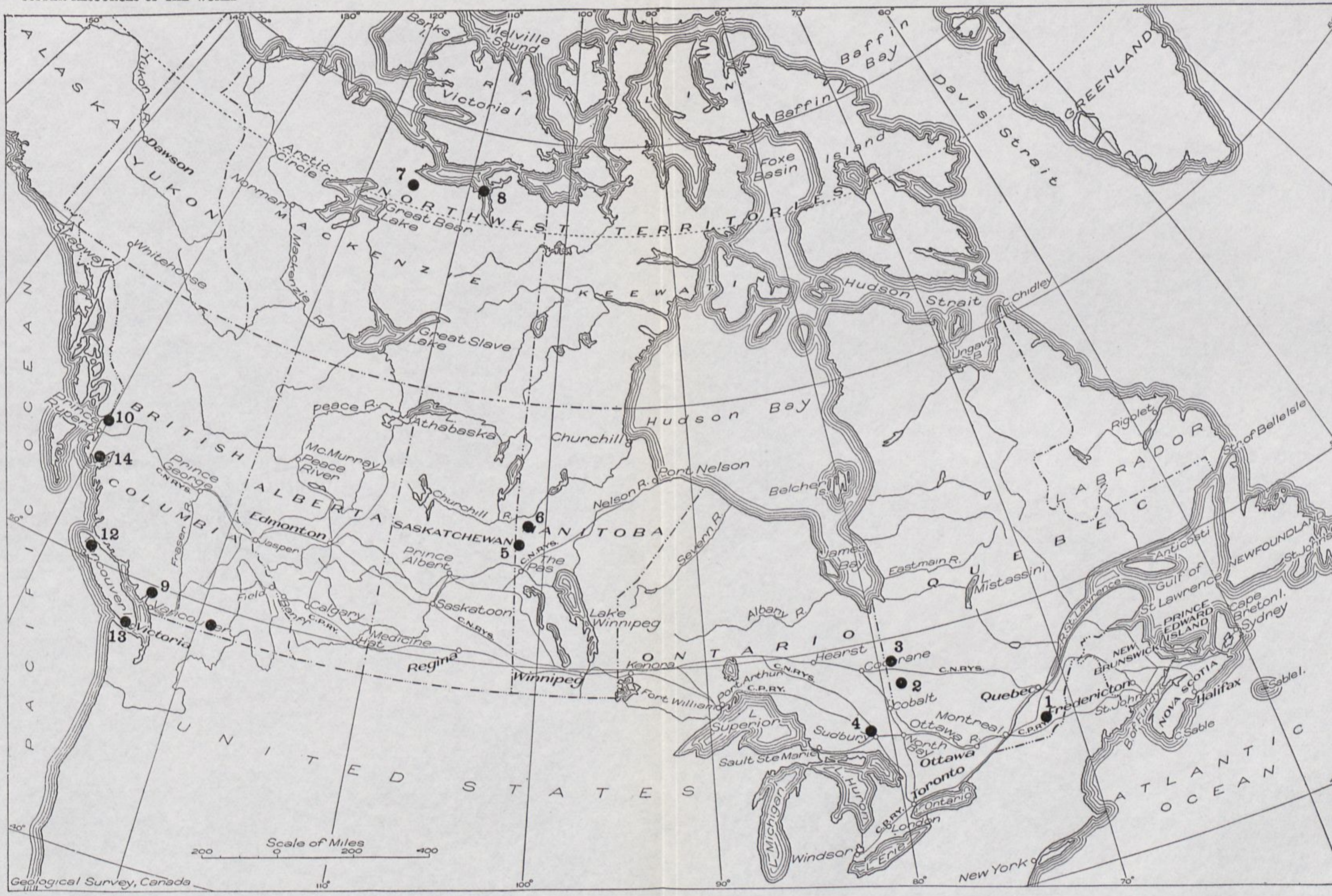
Arctic Archipelago and Hudson Bay lowland

The islands of the Canadian Arctic region cover a land area of more than 500,000 square miles. The higher regions of the larger islands consist largely of pre-Cambrian rocks. Strata of various ages from Cambrian to Tertiary are also known. No important deposits of copper have yet been located on these islands.

On the west side of Hudson Bay is a lowland underlain by nearly horizontal strata ranging in age from Ordovician to Mesozoic. This belt has a length in a northeasterly direction of 800 miles and a width of 100 to 200 miles and rises from sea level with a scarcely perceptible gradient to an altitude of about 400 feet. It contains no copper deposits.

Great Plains

The Great Plains of Canada extend from the Canadian Shield on the east to the Rocky Mountains on the west. At the American border they have a width of 800 miles, but 1,500 miles to the northwest, at the mouth of the Mackenzie River, the width is less than 100 miles. In the northwestern part of the region, between Great Bear Lake and the Mackenzie River, is the Franklin Range, composed of folded strata. Elsewhere throughout the region, however, the underlying rocks are nearly horizontal sediments of Paleozoic, Mesozoic, and Tertiary age. The region contains no known copper deposits.



THE COPPER DEPOSITS OF CANADA

1, Eastern Townships; 2, Noranda, Waite-Ackerman-Montgomery, Aldermac, Amulet, Newbec; 3, Normetal; 4, Sudbury; 5, Flin Flon, Mandy; 6, Sherritt-Gordon; 7, Coppermine River; 8, Bathurst Inlet; 9, Britannia; 10, Hidden Creek, Bonanza, Marble Bay; 11, Copper Mountain; 12, Coast Copper; 13, Sunloch; 14, Drum Lummon.

Cordilleran region

The Cordilleran region comprises the mountainous country bordering the Pacific Ocean. In Canada it has an average width of 400 miles, a length in a northwesterly direction of 1,500 miles, and an area of 600,000 square miles. It is made up of three principal zones—on the east, the Rocky Mountain range; along the coast, a broad belt of mountains known as the Coast Range; and between these two an intermediate belt composed of plateaus and mountain ranges. The Rocky Mountains have a maximum width of 100 miles, with many peaks ranging from 10,000 to 12,000 feet in height. The Coast Range varies in width from 50 to 100 miles, and with it are commonly included the outlying mountains of Vancouver and Queen Charlotte Islands. The mountains rise abruptly from the coast to peaks which along the axis of the range reach altitudes of 7,000 to 10,000 feet. The coast is very irregular, being bordered by islands and indented with fiords. The broad belt of plateaus and mountain ranges between the Coast Range and the Rocky Mountains is represented in the north by the Yukon Plateau, a gently rolling upland broken into a series of flat-lying ridges by valleys several thousand feet deep. In southern British Columbia the interior region is a plateau 3,000 to 4,000 feet above sea level, cut by valleys 1,000 feet or more in depth. On the west side this plateau either joins the Coast Range directly or is separated from it by the Cascade Range and other mountains; on the east between the plateau and the Rocky Mountains are a series of ranges separated by northwestward-trending valleys. Of these the Selkirk Range, with altitudes reaching more than 11,000 feet, is the largest.

The Cordilleran rocks range in age from pre-Cambrian to Recent. The Rocky and Mackenzie Mountains and the Ogilvie Range of northern Yukon are made up of pre-Cambrian, Paleozoic, and Mesozoic sediments, which were folded during the Laramide revolution of early Eocene time. The Coast Range consists largely of a complex batholith intruded in Jurassic and Cretaceous time into sediments and volcanic rocks of earlier Mesozoic age. The interior belt of plateaus and ranges is underlain by late Paleozoic, Mesozoic, and Tertiary sediments and volcanic rocks. The pre-Tertiary beds are cut by numerous deep-seated igneous rocks, and in several districts pre-Cambrian strata are exposed.

The following is a brief summary of the geologic history of the Cordilleran region. In pre-Cambrian time sediments now represented by limestones, gneisses, and schists were deposited in the Yukon region and in central British Columbia (Shuswap terrane). These have been altered by intrusives, and included with them may be metamorphosed phases not only of pre-Cambrian but also of later rocks. In late pre-Cambrian time another series of quartzites and related sediments accumulated along the site of the present Purcell Range. From the Cambrian to the Mississippian sedimentation progressed in the Rocky Mountain and Purcell region. In Pennsylvanian time sedimentation and volcanism took place to the west. During Triassic and Jurassic time sedimentation and volcanism on a vast scale occurred in the region from the Rocky Mountains westward to the Pacific Ocean. In late Jurassic and Cretaceous time the region was deformed. The Selkirk and Coast Ranges were formed, and the Coast

Range batholith was intruded. In later Cretaceous time sedimentation took place on both sides of the Jurassic ranges. The mountains were peneplaned and their granite cores unroofed in late Cretaceous time. The Laramide revolution in the Eocene produced the Rocky Mountains, uplifted the baseleveled surface to the west, and folded parts of the interior plateau region. Local igneous intrusions took place. In the Oligocene local movements with intrusions again occurred, accompanied by some mineralization, the copper ores of the Sunloch property, on Vancouver Island, being deposited in a shear zone in Oligocene gabbro. In the Miocene great fissure eruptions took place, and during the Pliocene there was more volcanism with general uplift and subsequent valley cutting. During the Pleistocene most of the region, except some of the higher portions, was covered by the Cordilleran ice cap, and the whole region was depressed. In Recent time there has been uplift ranging from 450 to 1,000 feet.

With regard to mineral deposits, the most important event in the history of the Cordilleran region was the intrusion of the Coast Range batholith, to which most of the metalliferous deposits of the region are related. The exposed parts of this middle Mesozoic batholith form a band averaging about 100 miles in width following in general the Pacific coast but curving off to the east in southern British Columbia. Mineral deposits occur in two general zones, one on each side of this granitic belt. The coastal portion, including the island fringe, has been termed the "Pacific belt"; the eastern zone is referred to as the "Interior belt." In southern British Columbia, where the batholith trends to the east, the southern zone has been called the "Boundary belt" and the northern zone the "Kootenay belt." The Pacific and Boundary belts are characterized chiefly by copper deposits, the Pacific including such camps as Anyox, Marble Bay, Quatsino Sound, and Britannia, and the Boundary belt including Copper Mountain, Phoenix, Deadwood, Rossland, and others. The eastern and northern borders of the batholith, comprising the Interior and Kootenay mineral belts, are noted particularly for their gold, silver, zinc, and lead ores.

Quebec

The copper production of Quebec has come from two regions—the Eastern Townships, where a mining boom began as early as 1859, and the recently opened Rouyn field of western Quebec, which came into production in 1927. Except for a small recovery from pyritic concentrates from the Eustis mine, the whole copper production of the Province is now obtained from the Rouyn field.

Eastern Townships

The existence of copper ore in the Eastern Townships was known as early as 1841, and production commenced before 1860. Until recently the annual output ranged from about 1,000,000 to 5,000,000 pounds. In the early years the ores were mined for their copper content alone, and during this period the known richer copper ores were to a great extent exhausted. At a later period, commencing about 1877, the deposits were worked both for their copper and sulphur contents, as well as for small quantities of gold and silver. The total production of copper from the region has amounted to about 125,000,000 pounds, largely from one property, the Eustis. The two other most productive properties were the Capelton, which finally closed in 1907, and the Weedon, which produced considerably from 1910 to 1920. The ores are essentially pyrite deposits.

The copper-bearing belt is 30 to 40 miles wide and extends in a northeasterly direction for 130 miles from the Vermont border to the Chaudiere River. It includes two systems of ridges and hills composed of schistose sedimentary and igneous rocks which, with associated less-deformed sediments, are of pre-Cambrian and early Paleozoic age. The country between these two lines of ridges, which are 20 to 25 miles apart, as well as that to the northwest and southeast, is occupied by sediments of Cambrian to Devonian age. The rocks are much disturbed, in places closely folded or even overturned. The larger copper deposits lie within or close to one of the two metamorphic zones.

The western upland belt is known as the Sutton Range. Northwest of this range, near Acton Vale, the Acton mine produced 12,000 tons of ore averaging 12 percent of copper. The ore occurred in a bed of cherty limestone 3 to 70 feet thick resting on dark slate 20 to 80 feet thick. These strata, which are of Ordovician age, are folded and faulted. Most of the ore occurred at three places within a length of 720 feet. The limestone was brecciated, with the fragments cemented by bornite, chalcopyrite, and siliceous matter. Of the many copper-bearing deposits within the Sutton Range only one or two have yielded more than a few tons of ore. At the Harvey Hill mine, opened in 1850, the schistose country rock was impregnated with copper sulphides along three zones, the widest not more than a few yards across. The deposit yielded a few thousand tons of ore with an average copper content of 14 to 30 percent.

The eastern range of schistose rocks, known as the Ascot or Stoke Mountain belt, contains many copper deposits, of which a few have furnished considerable ore. Most of the deposits lie in sericite schist or near the contact of zones of sericite schist and chlorite schist. The sericite schists in places grade into quartz porphyry, and the chlorite schists appear to represent altered igneous rocks such as diabase, andesite, and fine-grained diorite. In many places the sericite schists are mineralized with disseminated pyrite, smaller amounts of chalcopyrite, narrow veins of quartz carrying sulphides, and locally narrow stringers of sulphides.

The important deposits of this belt have been the Eustis, the Capelton, and the Weedon. The deposits are lenslike replacement masses arranged en échelon. At the Eustis individual lenses of ore have strike lengths of 100 to 400 feet and thicknesses ranging from 15 to 60 feet. They follow the schistosity and dip at angles of 25° to 70°. One ore body was followed along the dip for 800 feet. The workings go to a depth of 4,700 feet along the dip, and the ore shows no sign of diminution at that depth. The ore is pyrite intimately admixed with a little chalcopyrite, silicate gangue, and quartz. The precious-metal content is negligible. The old records show an average of 2 to 3 percent of copper. The average at present is higher, but not high enough to permit working the mine for copper alone, and it has been necessary to sell the sulphur as well. In addition to the copper-sulphur ores some lenses of pyrite carrying a little copper have been opened up to the northeast during recent years from the 3,400-foot level downward. The largest lens has been estimated as 120 feet wide, 20 feet thick, and 1,000 feet long along the dip. Two smaller lenses beneath this contain about 2 percent of copper. The sulphur content of the Eustis ores is 40 to 45 percent. The largest single lens in the belt, 570 feet long and about 50 feet in maximum thickness, was in the Weedon mine. The ore was granular pyrite carrying a little chalcopyrite, sphalerite, and galena irregularly distributed, in places a little pyrrhotite, and small amounts of gold and silver.

Central Gaspe

On the headwaters of Berry Mountain and Brandy Brooks, tributaries of the Cascapedia River, in central Gaspe, a mineral field has been opened up and considerably developed. The deposits are chiefly zinc and lead, in places with considerable chalcopyrite, and there is a possibility that more extensive copper deposits may be found. The apparently most promising claims are held by Lyall & Beidelman, of Montreal, and by the Federal Zinc & Lead Co., also controlled by them.

The mineralized region is a deeply dissected wooded plateau of Lower Devonian limestone, argillite, quartzite, and tuffs overlain by volcanic flow rocks, which are in turn overlain by the Middle Devonian Gaspe sandstone series. The Lower Devonian sediments are cut by dikes and masses of porphyry and syenite, believed to be early differentiates of the Tabletop granite batholith (Devonian), which lies northeast of the area.

The deposits are veins and breccia zones in the Lower Devonian sediments. The veins, which are younger than the syenite intrusives, cut them in places or follow the intrusive contact and are probably genetically related to the plutonic rocks of the area.

In the most extensively developed deposits the vein minerals are chiefly iron-poor sphalerite with less galena in a gangue of quartz and subordinate carbonate. In places the galena occurs in large masses.

Pyrite, marcasite, and chalcopyrite are present in minor amounts in most of the veins, and stringers of solid chalcopyrite occur locally. Recent development in the Brandy Brook region indicates that in places the copper is more abundant than the zinc and lead. At present, owing to the low price of the base metals, no work is being done on any of the deposits, and up to date there has been no production.

Chalcopyrite has also been found near the headwaters of the York River, and native copper in small amounts occurs south of Matane.

Western Quebec

The copper-gold-zinc region of western Quebec lies near the Ontario border, in Abitibi and Temiskaming Counties. The main line of the Canadian National Railways, constructed in 1915, runs through the region. A branch line was run in 1925 from Taschereau to Rouyn, a distance of 44 miles. Spur lines connect the Waite-Ackerman-Montgomery and Amulet properties with the main line. In 1926 the Nipissing Central Railway, a subsidiary of the Temiskaming & Northern Ontario Railway, was extended from Cheminis, on the interprovincial boundary, to Rouyn.

The rock succession of the region is as follows:

Geologic section in western Quebec

Quaternary.	Postglacial.	Clay, silt, and sand.
	Glacial.	Boulder clay; morainic deposits.
Keweenawan (?).	Nipissing diabase.	Dikes.
Huronian.	Cobalt series.	Conglomerate, graywacke, arkose, and argillite.
Great unconformity		
Pre-Huronian.	Intrusives.	Basaltic dikes. Later gabbro. Altered peridotites. Granitic intrusives (granite, granodiorite, augite syenite, porphyritic syenite, gray and red syenite porphyry). Quartz diorite (older gabbro). Post-Temiskaming folding. Diorite porphyry. Amphibolite.
	Timiskaming series.	Conglomerate, graywacke, and lavas.
	Probable unconformity	
	Keewatin series.	Basalts, andesites, dacites, rhyolites, tuffs, and metamorphosed sediments.

The copper deposits of the region are chiefly sulphide replacement deposits; the few veins known in the region are comparatively small. The sulphide ore bodies have been found only in the Keewatin rocks, all within 30 miles of the interprovincial boundary. Intrusions of quartz diorite, granodiorite, and a coarse porphyry that cut these rocks are largely confined to this region, suggesting that one of these intrusives may have been the source of the mineralizing solutions.

The deposits vary greatly in size and show all degrees of replacement. Many consist of practically solid sulphides, with little or no country rock remaining. These range from masses 10 to 20 feet long and 1 or 2 feet in width to great bodies several hundred feet long and as much as 200 feet in width. Other deposits contain unreplaced fragments of the original rock in greater or less amount, and still others are disseminated deposits, not yet of economic importance.

The sulphides are pyrite, pyrrhotite, sphalerite, and chalcopyrite, and with them magnetite is commonly associated. The proportions of the sulphides vary greatly, and any one may locally occur almost to the exclusion of the others. Commonly, however, pyrite and pyrrhotite dominate, with more or less chalcopyrite. The order of deposition appears to have been pyrite, magnetite, pyrrhotite, and sphalerite or sphalerite and chalcopyrite, with a second generation of pyrite in places almost contemporaneous with the chalcopyrite. Each of these minerals replaced the preceding ones to a greater or less extent.

The ore bodies are commonly irregular when viewed in three dimensions. They are usually lenslike, but in many the length is not more than two or three times the width, so that the lenses are stout, resembling cones or pipes. There is apparently a tendency, at least in some of the larger properties, for the ore lenses to lie vertically below or parallel to one another. A possible explanation of such an arrangement is that solutions rising along some fissure replaced successive beds of some easily replaceable rock. The rocks replaced by the ore bodies are all either lavas, tuffs, or breccias of rhyolitic and dacitic composition. Of these the fragmental rocks were invariably replaced wherever they were available, doubtless because of their ready permeability. The deposits of Noranda Mines, Aldermac, and Robb-Montbray and most of the minor deposits have been formed by the replacement of such breccias, tuffs, or sheared rocks. Those on the Amulet and Waite-Ackerman-Montgomery are in massive lavas, the replacement no doubt having been localized by structure. Profound alteration accompanied the sulphide mineralization; large masses of the country rock were highly silicified and later chloritized. On the Amulet property a rock known as "dalmatianite" from its peculiar spotted texture was formed by the alteration of rhyolite. Silicification and chloritization probably took place at the time of the chalcopyrite and sphalerite mineralization rather than during that of the iron sulphides.

There is little definite information regarding the source of the copper-bearing solutions. They were evidently highly heated and ascended from great depths from the magmatic reservoir that supplied some one or other of the intrusives.

Noranda Mines

Location and history.—The property of Noranda Mines, Ltd., comprising a block of 16 full claims and several fractional claims, lies directly west of Osisko Lake in Rouyn Township. The copper deposits are at the Horne mine, in block 15, near the west shore of Osisko Lake.

This property was staked in 1920 by E. H. Horne, acting for a small syndicate. The earlier discoveries consisted of bands of rhyolite rather heavily impregnated with grains of pyrite and a little chalcopyrite lying west and southwest of what is now shaft 2 and a wide vein of massive pyrites near Horne Creek. The widespread mineralization encouraged prospecting, and in August, 1922, Mr. Horne and his associates optioned the property to the syndicate which shortly afterward became Noranda Mines, Ltd. Late in 1923 trenching disclosed the large body of copper and iron sulphides now known as "ore body A." Shaft 1 was begun on this ore body, and a second shaft was begun about 1,050 feet northwest of it, on another mass of iron sulphides located by surface prospecting, known as "ore body F." Shaft 2 was sunk to the 100-foot level, where enough lateral work was done to define ore body F on that level and to cut into a body of zinc ore north of ore body F. Several ore bodies were explored on levels run from shaft 1. Later a long drift, the Montreal, was driven to connect shafts 1 and 2 on the 100-foot level. This drift cuts a large body of pyrite and pyrrhotite some 150 feet wide, "ore body H." Other sulphide masses, some copper-bearing, have also been found by surface work. During 1927 a three-compartment shaft, No. 3, was begun, to serve for rapid extraction of ore. It was sunk to the 500-foot level, and stations were cut at the levels, the development drifts enlarged for motor haulage, and raises driven in the ore bodies. In 1928 shaft 3 was deepened to 1,040 feet, and as it was found to enter the large ore body H above the 975-

foot level, a new shaft, No. 4, was begun about 900 feet northwest of shaft 3. In 1929 and 1930 shaft 4 was deepened to 1,557 feet. By the end of 1931 shaft 3 was 2,527 feet deep. An important development of that year was the finding of a large massive sulphide ore body, the "Lower H," underlying the original lens of ore body H, which bottomed at a depth of about 1,300 feet. Drilling from the surface also outlined another body of ore known as "ore body G." In 1932 sinking on shaft 3 was resumed, and horizontal work and diamond drilling were carried out to explore the Lower H ore body. New developments above the 1,975-foot level proved a greater tonnage of new ore than was mined during the year, so all the ore developed in the Lower H ore body between the 1,975-foot and 2,475-foot levels was additional to the previously reported reserves.

Early in 1928 a small concentrator was erected for the treatment of ores too lean for direct smelting. By 1930 the capacity was increased to 1,000 tons daily. The smelter began operations in December, 1927. Since March, 1931, all the copper has been shipped in the form of anodes to the refinery in Montreal East.

Production from Horne mine of Noranda Mines, Ltd.

Year	Ore and concentrate smelted (tons)	Fine copper (pounds)	Gold (ounces)	Silver (ounces)
1927	10,740	552,345	767	2,644
1928	271,926	33,065,261	52,949	186,277
1929	428,221	51,223,115	68,732	334,279
1930	734,072	75,509,373	117,393	691,920
1931	765,544	62,859,355	253,363	558,801
1932	918,567	63,013,485	341,350	619,597

Ore reserves.—Ore blocked out above the 2,475-foot level was estimated at the end of December, 1932, to be as follows:

	Ore (tons)	Gold per ton	Copper (percent)
Direct smelting ore	5,750,000	$3.27	7.60
Concentrating ore	15,800,000	4.00	1.16
Siliceous fluxing ore	900,000	4.17	5.28
	22,450,000		

These reserves, over double those known at the end of the previous year, indicate a content of $85,755,500 in gold and 1,240,560,000 pounds of copper. At the present rate of production they give a life to the mine of 20 years. It is expected that the reserves will be still further increased. The mine is only partly developed above the 1,975-foot level, and practically no work has been done below that level except in the Lower H ore body. Drill holes northwest of Lower H have cut high-grade ore. Drilling also shows that the high-grade zone of the Lower H extends at least 200 to 300 feet below the 2,475-foot level.

Geology.—The rocks on the Horne property (fig. 3) consist of rhyolite, dacite, lavas, breccias, and tuffs, all of Keewatin age, intruded by dikes of quartz diorite, syenite porphyry, and later gabbro. The rhyolites are light-colored and may be massive or brecciated; the dacites resemble them but are usually darker, containing more chlorite and less quartz. These volcanic rocks have been drag-folded

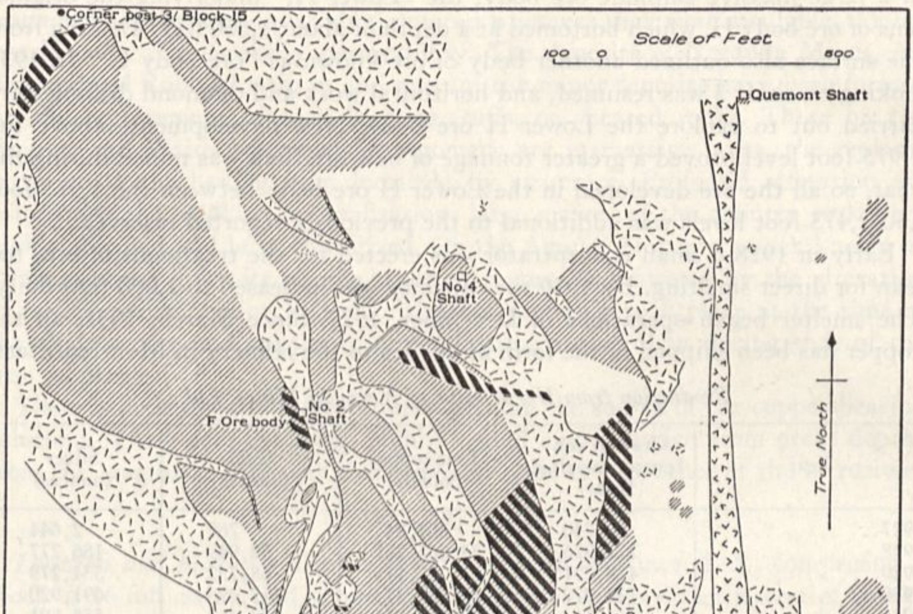


FIGURE 3.—Surface geology, Horne mine, Noranda, Quebec. (After Canada Geol. Survey Mem. 166.)

over a width of about 1,900 feet; outside the drag fold the prevailing strike is roughly east, whereas within it the strike is north-northwest between Horne Creek and an east-west line drawn 100 to 150 feet north of shaft 3 and northeast between this line and another drawn roughly 200 to 300 feet south of shaft 1. The north edge of the drag fold is a fault striking N. 77° E. Other faults, trending north to northeast and probably subsidiary to the main fault, occur throughout the mine, and all appear to show the same (left-hand) relative movement.

Numerous dikes of quartz diorite are found both on the surface and in the mine. They range in width from a few inches to 300 feet. Although they tend to follow in general the bedding of the lavas, their strike varies considerably. North of shaft 3 the dominant trend is north-northwest; south of it, northeast. The dip averages 40°–50° E., but it is not uniform, changing from nearly vertical in one place to nearly flat in another. The dikes anastomose complexly.

Small dikes of syenite porphyry occur in a few places, the main one just north of shaft 1 on the first level, striking about east and dipping about 60° N. The matrix of the rock is dark gray, tinged reddish by numerous feldspar phenocrysts. Two or three dikes of the later gabbro are also known. One, about 80 feet wide, passes about 125 feet east of shaft 1, trending slightly west of north. It has been cut on several levels in the underground workings and is known to dip steeply. A second dike of similar size lies on block 25, close to the north boundary of the property, and a third (possibly a continuation of the second) crops out 450 feet east of the first dike, forming a low eastward-trending ridge 200 feet long and 40 feet wide. The later gabbro or diabase is fairly fresh, shows pronounced ophitic texture, and is composed of labradorite and augite in about equal amounts with 3 to 5 percent of magnetite or ilmenite.

Most of the faults are evidently later than the quartz diorite, and at least some are later than the syenite porphyry. In the mine no large fault has been found to cut the later gabbro, but there are small faults clearly later than that rock. In many places these small faults are deflected where they meet the later gabbro dike and run along its edge, crushing the edge slightly in places.

Ore deposits.—The sulphide bodies have replaced breccia or tuff, commonly the more chloritic dacite breccias. At the margin of the ore bodies grains of sulphide, commonly pyrite, appear in the country rock and gradually become more numerous until the whole becomes a solid mass of sulphide enclosing a few unreplaced fragments of the original rock. The massive lavas and dike rocks, particularly the quartz diorite dikes, were not easily replaced and commonly form walls to the ore bodies.

The dominant strike of the sulphide bodies is northeast, corresponding roughly to that of the volcanic rocks, and probably the ore bodies were localized along lines of faulting and shear. There is some direct evidence of older faults. In two places underground, close to ore bodies H and J, unfractured stringers of pyrite are found in shatter zones of faults, suggesting that the faulting took place prior to the introduction of the pyrite. As the pyrite-pyrrhotite masses were formed between the intrusion of the quartz diorite and that of the syenite porphyry, these faults must be older than the other faults of the mine.

The sulphides are pyrite, pyrrhotite, and chalcopyrite in varying proportions, with a little magnetite and sphalerite in places. The order of deposition was pyrite, pyrrhotite, sphalerite, and chalcopyrite, each replacing more or less the earlier minerals. Small veinlets of iron sulphides traverse and alter the quartz diorite, showing that the sulphides are later than the intrusion of these dikes. At the Aldermac mine the syenite dikes are later than the iron sulphides, and it is assumed, although not directly proved, that this relation exists at the Horne mine also. Veins of chalcopyrite, however, cut and alter the syenite porphyry and also cut into the chilled edge of the later gabbro; the chalcopyrite is therefore later than both these intrusives. The time of introduction of the sphalerite is less certain. Some ore bodies are impregnated throughout with chalcopyrite; others only locally. It is therefore important to explore every body of sulphides both along the strike and down the dip, for barren sulphides may pass into ore at depth or at either end.

The gold in the Horne ores is very erratically distributed. As the sulphide bodies carry gold in notable quantities on only two properties of the region, the Horne and Robb-Montbray, it appears that the gold was derived from a purely local source. In the Horne mine the gold tenor varies quite independently of the chalcopyrite and is equally independent of the other sulphides. On the other hand, it has been shown by tests on sulphides from ore body F that the pyrrhotite carries no gold and that all the gold is associated in some way with the pyrite and chalcopyrite. It would appear, therefore, that the gold was introduced in a local and erratic manner into the sulphide bodies and that selective precipitation caused its association with the pyrite and chalcopyrite rather than with the pyrrhotite.

The ore bodies are large lenses of rather irregular outline, generally northeast strike, and steep southeast dip.

Ore body A was the first mass of high-grade ore found on the property. Shaft 1, sunk on this body, continued in ore almost to the first level, where it passed through the bottom of the lens. Exploration on the first level led to the discovery some 200 feet northeast of the shaft of what was termed "ore body D," later found to be part of a single continuous mass with A. Both northeast and southwest of the shaft the mass dips below the first level, so that the shape is that of an inverted U. On the first level ore body A–D lies between two quartz diorite dikes about 40 feet apart. On the northeast ore body D and the dikes on each side of it are cut by the north-south dike of later gabbro. Generally the ore ends abruptly against the chilled edge of the later gabbro dike, but at one place a tongue of chalcopyrite about 6 inches long and 1 inch thick projects into the gabbro, suggesting a later origin for the chalcopyrite. The copper content is high in ore body A–D, and gold averages about $5 a ton. In places, particularly at the northeast end, the ore is almost pure chalcopyrite.

Ore body B, a thick lens about 110 feet long and at least 50 feet wide on the first level, lies just west of ore body A, the two apparently being separated by a dike of quartz diorite. It is nearly parallel to ore body A–D and like it is completely walled in by quartz diorite. The ore is massive sulphide, with slightly less copper than A–D but averaging about $8 a ton in gold.

Ore body C on the first level has a length of 210 feet and a maximum width of about 50 feet. It lies about 100 feet southeast of ore body A, strikes N. 55°–60° E., dips about 60° SE., and rakes strongly to the northeast. It is cut on the second and third levels by the north-south dike of later gabbro. The ore body grades at its ends into mineralized dacite or rhyolite breccia.

Ore body E is about 250 feet east-northeast of C, and between them on the surface and first level is the north-south dike of later gabbro. On the first level ore body E is about 200 feet by 50 feet in plan and strikes N. 60° E. Between the surface and the first level it dips very steeply southeast. On the second level its dimensions are reduced to 175 feet by 15 feet, and on the third level it is merely a pipe 6 or 8 feet in diameter. Unlike most of the other ore bodies the E mass is not bounded by quartz diorite but is surrounded by a light-gray siliceous, supposedly tuffaceous rock. Numerous relics of this rock in all stages of replacement show that the ore body was formed by replacement of it. There is practically no pyrrhotite in ore body E; the original sulphide mass was pyrite, which was replaced by chalcopyrite to form the ore.

The large ore body F strikes north and dips steeply east. Shaft 2 has been sunk on it, and drifts on the 100-foot level prove its length there to be about 175 feet and its maximum width 50 feet. The ore consists mainly of pyrite and pyrrhotite with a little chalcopyrite, carrying gold averaging about $8 a ton. At the north end ore body F is in contact with rhyolite, but a few inches of rhyolite breccia at this contact suggests that the sulphides replaced a breccia almost to its contact with massive rhyolite. At the south end the ore is bounded by a quartz diorite dike 5 to 6 feet thick, which dips about 10° N. and then trends sharply downward into the floor of the drift. The sulphides lie directly on the dike, which is cut by many pyritic fissures, some several inches wide. On the east side the ore body is also bounded on the first level by a narrow dike striking N. 27° W. and dipping 55° E. The massive sulphides stop abruptly at the dike, beyond which is normal dacite.

Ore body H on the first level is about 150 feet wide, strikes N. 60° E., and dips southeast. On the surface its southeast border passes about 150 feet northwest of shaft 3, and it is cut by several large dikes of quartz diorite. On the surface and first level it is almost wholly pyrite and pyrrhotite with a little chalcopyrite, but on the third level some parts are sufficiently enriched to be ore. Shaft 3 entered the ore body a little above the 975-foot level, where it was a high-grade copper-gold ore. The body was bottomed at about 1,300 feet.

In 1931 a large massive sulphide ore body, known as the "Lower H" or "No. 21" ore body, underlying the original ore body H, was found by diamond drilling, and shaft 3 was also sunk to explore it further. The ore body was encountered at a depth of 1,600 feet and continued to 2,527 feet, the depth of the shaft at the end of 1931. The ore body has a length of over 600 feet and a maximum width of 600 feet, with a good tenor in both gold and copper.

Ore body J, a mass of zinc ore, is exposed in a drift on the first level about 75 feet northwest of the north end of ore body F. It is about 25 feet wide along the drift and consists principally of pyrite and sphalerite that is later than and replaces the pyrite.

Other masses of ore or of barren sulphides upon which a little work has been done also occur on the property. In addition to the copper-gold ores, the company has on its Chadbourne claim a promising gold deposit.

Waite-Ackerman-Montgomery Mines

The property staked in March, 1925, by I. H. C. Waite, C. H. Ackerman, and T. Montgomery consists of 28 claims covering 2,379 acres, partly in Duprat Township and partly in Dufresnoy Township. Later in 1925 an 85 percent interest in the property was sold to N. A. Timmins, who transferred it early in 1927 to Noranda Mines, Ltd. This company then organized a subsidiary company, known as Waite-Ackerman-Montgomery Mines, Ltd., to operate the mine.

The original discovery was accidental. Mr. Montgomery in crossing a clay-filled valley, then a muskeg, saw an exposure of ore beneath the upturned roots of a fallen tree. It proved later that this was almost the only place where ore is near enough to the surface to be exposed. Trenching in 1925 proved the presence of ore over an area roughly 100 feet from north to south by 200 feet from east to west. In the following winter diamond drilling further outlined the ore body, and in 1927 a two-compartment shaft, since sunk to 1,000 feet, was commenced. Levels have been run at 187, 300, 500, 600, and 700 feet.

The upper or surface ore body is a roughly lenticular mass, dipping about 25° SE., composed of pyrite, chalcopyrite, sphalerite, and some pyrrhotite. The central core of the ore body is rich in chalcopyrite, surrounded by a leaner shell of iron sulphides and sphalerite. Other ore bodies occur vertically beneath this deposit. They are lenses about parallel to the surface ore body, having a flat southeast dip and a northeast strike. They are very irregular in shape and are cut by many diabase dikes. At the end of 1931 the estimated ore reserves amounted to 467,350 tons averaging 6.08 percent of copper and with a negligible zinc content, and in addition 300,000 tons averaging 11.52 percent of zinc and with a negligible copper content.

Production began in September, 1928, and ore was shipped to Noranda for treatment. The first shipments carried much zinc and had to be concentrated. Afterward it was found possible by careful mining to ship direct-smelting ore carrying from 8 to 10 percent of copper and 4 to 6 percent of zinc, though occasionally the zinc content was slightly higher. An average of 4,000 tons of ore was shipped monthly until May, 1930, when, owing to the low price of copper, production from the surface ore body was discontinued. For the remainder of 1930 and in 1931 shipments were limited to the higher-grade ore broken in development work.

The geology in the immediate vicinity of the mine is extremely complex. The oldest rocks are andesitic Keewatin lavas, but these are present in comparatively small quantity. Most of the rocks are dioritic or diabasic intrusives. Four dioritic and one rhyolitic intrusion have been recognized. All these diorites or diabases are to be classed with the older gabbro or quartz diorite.

The ore bodies were formed by the replacement of the andesitic lavas. They do not appear to have replaced any of the intrusives to any notable extent.

Aldermac Mines, Ltd.

The property of Aldermac Mines, Ltd., consisting of 7 claims in the west half of Beauchastel Township close to the east-west center line, originally belonged to the Towagmac Exploration Co., which discovered the ore body by dip-needle exploration in the fall of 1925. The property was incorporated in 1927 under the name "Aldermac Mines, Ltd." Noranda Mines held 60 percent of the stock, and the Towagmac Exploration Co. 35 percent. Toward the end of 1929 arrangements were made whereby control of the company reverted to the Towagmac Exploration Co. A shaft was sunk to a depth of 1,125 feet; levels were run at 125, 250, 500, 750, and 1,125 feet; and a considerable amount of diamond drilling was done. Six ore bodies have been opened up. In 1931 a concentrator with a rated capacity of over 500 tons a day was erected. A mill run indicated that 60 percent of the total ore milled can be recovered in the form of pyrite concentrate and 90 percent of the copper recovered in a 20 percent copper concentrate. Enough ore has been proved above the 720-foot level to supply the concentrator for 10 years.

The rocks of the region include Keewatin flows and tuffs, mostly acidic in composition, invaded by dikes of quartz diorite, syenite porphyry, and later gabbro. Ore bodies 1 and 2 lie in a dark-gray rock filled in places with small rounded nodules or spots averaging about one-eighth of an inch in diameter. No. 1 is a small flat-lying shatter zone filled with pyrite and some chalcopyrite. No. 2, about 200 feet to the north, is a lens traceable on the surface for about 130 feet and striking due east. The middle 2 feet of the lens is almost solid sulphides, and the surrounding rock is heavily impregnated with sulphides throughout a total width of about 15 feet.

Ore body 3 does not crop out but has been opened up on the 125- and 250-foot levels and cut by a drill hole from the surface at the 375-foot level. It is a lens striking roughly east and dipping about 60° S. On the 125-foot level it has been proved for a length of 130 feet and has a maximum width of 40 feet of solid sulphide. On the 250-foot level it is over 200 feet long and about 55 feet wide. This work indicates a probable reserve of 220,000 tons with an average copper content of 2.68 percent. On the 500-foot level two lenses, possibly the downward extension of ore body 3, were opened up. One of these, the Easterly, is 60 feet long and 16.5 feet wide and averages 1.04 percent of copper. The other, the Westerly, averages 1.86 percent of copper for a length of 30 feet and a width of 10 feet. Hard massive rhyolites occur on each side of ore body 3, and the sulphide mass was probably formed by replacement of a lens of breccia lying between two rhyolite flows. The sulphides are pyrite, pyrrhotite, and chalcopyrite. Practically no sphalerite is present.

Ore body 3 shows some interesting relations of ore to porphyry dikes. Three dikes of syenite porphyry, offshoots of the larger mass lying directly to the northeast, clearly intrude the ore on the first level. The edges of the dikes are strongly chilled over widths of 3 or 4 inches, as is particularly well shown in the reduction in the size of the feldspar phenocrysts. In places also the porphyry sends small stringers into the mass of sulphides. On the other hand, veinlets of chalcopyrite penetrate the porphyry dikes, showing that the chalcopyrite was introduced at some time after the intrusion of the porphyry.

Ore body 4 lies vertically beneath No. 3. Its top lies somewhere between 250 and 400 feet below the surface. The shaft enters it at a depth of 412 feet and leaves it at 698 feet. On the 500-foot level the body has a length of about 240 feet and a maximum width of 140 feet. If the ore body is continuous from the 250-foot level to the 720-foot level, it contains 1,017,961 tons with an average copper content of 1.65 percent and a little gold and silver. The ore contains over 75 percent of iron pyrite and comparatively little pyrrhotite. The probable tonnage in ore bodies 3 and 4 is 1,237,960 tons of ore averaging 1.82 percent of copper.

On the 500-foot level ore body 5 has been opened up for a length of 27 feet. It has a width of 4½ feet and shows 2.3 percent of copper. On the 1,125-foot level low-grade massive sulphides have been cut in ore body 6. The sulphides are cut by narrow porphyry dikes, near which the copper content is much higher. The ore body as blocked out by drill holes shows 2,370 tons of 1.9 percent copper per foot of depth. This indicates a large additional tonnage below the 720-foot level.

Amulet Mines, Ltd.

Amulet Mines, Ltd., owns a group of 17 claims, comprising about 1,500 acres, extending across from Dufresnoy Township into Duprat Township. The first discovery was made in 1924, and other ore lenses were later located by trenching and drilling. A 300-ton mill was built during the winter of 1929–30 and a railway spur run into the mill site. The mill operated from April 15 to October 20, 1930, when the plant was closed down. During this period 60,291 tons of ore averaging about 4 percent of copper and about 18 percent of zinc was treated. The estimate of the ore reserves indicated by diamond drilling June 30, 1930, was as follows:

Ore reserves of Amulet Mines, Ltd.

Ore body	Copper (percent)	Zinc (percent)	Gold (dollars per ton)	Silver (ounces per ton)	Ore (tons)
A............	2.80	9.10	1.86	1.80	160,448
B............	3.51	6.44	.58	2.64	37,286
C............	2.60	16.00	.51	3.84	169,997
D............	1.59	7.33	.30	2.00	6,250
E............	.56	21.48	.27	1.90	4,500
F............	4.29	11.05	.57	1.53	148,672
	3.17	11.78	.94	2.44	527,153

The rocks on the Amulet claims are mainly Keewatin rhyolites, with some dacite and a little andesite exposed on the broad summit of the Dufault anticline. There are several rhyolitic flows of slightly different composition. All are hard, fine-grained rocks, commonly amygdaloidal, and some are porphyritic. In places a peculiar spotted rock called "dalmatianite" occurs. It appears to be the product of alteration of both rhyolite and dacite by ore-bearing solutions.

The six ore bodies known on the property are rather flat, pancake-shaped bodies, conforming roughly in attitude to the lavas. Most are irregular in outline.

They consist of masses of solid sulphides with very little gangue and replace the altered lavas. The sulphides, named in order of age, are pyrite and pyrrhotite, zinc blende, and chalcopyrite.

Normetal Mining Corporation

The Normetal Mining Corporation, controlled by the Mining Corporation of Canada, owns the property of the former Abana Mines, Ltd., a group of 12 claims in the northern part of Desmeloizes Township near the Ontario boundary, 13 miles north of Dupuy, Quebec, a town on the main line of the Canadian National Railways. The deposits are lenses and disseminations of zinc blende and chalcopyrite in a shear zone in rhyolitic schist. The shear zone has a width of 75 to 150 feet, strikes about N. 60° W., and dips 70°–75° NE. Cutting through the shear zone near the center of the property is a diabase dike striking approximately north and having a width of 180 feet on the 300-foot level. Faulting, probably later than the intrusion of this dike, has thrown the section east of the dike 150 feet to the north, the zone maintaining its regular strike on both sides of the fault. Another dike of older and much-altered gabbro or diabase parallels the shear zone on its footwall side at a distance of 50 to 75 feet. This dike has an average width of 50 feet and is locally mineralized with pyrite, sphalerite, and chalcopyrite.

The ore bodies lie in and parallel to the shear zone. They are definite and persistent and west of the main dike have been followed by underground work to the 550-foot level and by drilling to 1,200 feet. They consist of shoots or lenses of pyrite, chalcopyrite, and sphalerite, with gold and silver accompanying the copper and zinc minerals, which are probably younger than the pyrite replacement. The pyrite is barren of precious metals. A little galena and tetrahedrite are present. The gangue is schist and quartz.

Five ore bodies are known. West of the dike Nos. 1 and 2, replacing sections of the shear zone, have been developed on the 100- to 550-foot levels and by several raises. Both these ore bodies are small on the 100-foot level, averaging 4 feet wide and about 100 feet long, and are 60 feet apart. On the 200-foot level the combined length of the two is 350 feet, the widths are 10 feet for No. 1 or the footwall ore body and 5 feet for No. 2, and they are 40 feet apart. On the 300-foot level the combined length is 400 feet; each averages 8 feet wide, and they are 30 feet apart. From the fact that the two ore bodies converge and from evidence afforded by drill holes below the 300-foot level it was thought that the two would unite at about the 500-foot level. Further development on the 425- and 500-foot levels, however, proved that this was only partly true. The apparent joining is due to greater replacement in portions of the intervening schist and pyrite, so that in general the two ore bodies below the 300-foot level are distinct and roughly parallel, separated by a varying width of slightly mineralized and low-grade material consisting of unreplaced schist with considerable massive and disseminated pyrite, the whole mineralized width on the lower levels being 50 to 65 feet. Below the 300-foot level the two ore bodies both lengthen and widen. Ore body 1 is considered zinc ore, although above the 300-foot level there is sufficient copper on the hanging wall to allow it to be mined as copper ore, in conjunction with ore body 2.

The zinc content increases with depth from about 15 percent to 21.6 percent on the 550-foot level; the copper decreases progressively from 3 percent on the 200-foot level to less than 1 percent on the 550-foot level. No. 2, a copper ore body, contains 8½ percent of copper on the 200-foot level, 6½ percent on the 300-foot level, and 5.68 percent on the 500-foot level. The zinc content of body 2 apparently increases progressively from 4 percent on the 300-foot level to 7 percent on the 550-foot level, the zinc occurring mainly in the footwall section of the ore.

Ore body 3 lies east of the main or cross dike. It has been developed by drifting, raising, and crosscutting on the 300-foot and 200-foot levels, where it averages from 20 to 28 feet in width and carries 15 percent of zinc, 1¼ percent of copper, and some gold and silver. There is an upper lens higher in copper, but this cannot be mined separately and must be included in the zinc ore. Drilling to 500 feet suggests that ore body 3 becomes lower in grade at that depth.

Ore body 4 is a short, narrow showing (undeveloped) of copper ore lying east of No. 3.

Ore body 5 is west of No. 2 and is copper ore. In calculating tonnages it is grouped with No. 2.

The following is a summary of the ore reserves as of February, 1930:

Ore reserves of Normetal Mining Corporation

	Ore (tons)	Gold (ounce per ton)	Silver (ounces per ton)	Copper (percent)	Zinc (percent)
Copper ore (body 1 above 300-foot level; body 2 from 100 to 600 feet)...	190,100	0.04	4.80	5.05	8.3
Zinc ore (body 1, 300 to 600 feet; body 3)........................	275,400	.04	5.15	1.16	17.1
Dump ore:					
Copper dump (assumed).........	4,300	.04	4.80	5.05	8.3
Zinc dump (assumed)...........	7,400	.04	5.31	2.28	17.1
	477,200	.04	4.87	2.70	13.2

Newbec Mines, Ltd.

Newbec Mines, Ltd., holds some 32 claims, covering about 2,000 acres, in Dufresnoy Township. A shaft has been sunk near the middle of block 8, five-eighths of a mile northwest of Dufault Lake, levels turned at 75, 125, 250, and 375 feet, and considerable diamond drilling done. Operations were suspended in February, 1931.

The rocks include dacitic lavas, minor intrusives, and the Dufault granodiorite. The minor intrusives include older gabbro or diorites of at least two ages and a very siliceous quartz porphyry which is older than both gabbros but intrudes the lavas. A small fault is prominent in the workings. It strikes N. 70° E., dips 82° N., and cuts all the rocks present. The ore body at the surface filled the fault fracture, appearing as a vein of chalcopyrite and other sulphides, about a foot in width. Between the surface and the 250-foot level it forms an irregular pipe. The mass is not large; its cross section on some levels is about 30 feet in length and 5 to 10 feet in width. The ore averages 5 or 6 percent of copper. It is made up of chalcopyrite, pyrite, and pyrrhotite, with practically no sphalerite. It is probable that with copper at a minimum of 15 cents a pound the ore could be mined at a profit.

Sudbury area

History

The Sudbury area is one of the most productive mining regions of Canada and indeed of the world; in addition it presents features of unique geologic interest. It contains deposits of two main types—copper-nickel ores at or near the lower border of an intrusive igneous sheet and zinc-lead-copper ores concentrated along fault planes and probably related to the same intrusive. The region produces over 90 percent of the world's nickel; it is also one of Canada's largest producers of copper and supplies all the platinum produced in Canada.

Sulphides carrying nickel and copper were first noticed in 1856 by Salter, a land surveyor, and Murray, of the Geological Survey of Canada, near the site of the present Creighton mine. It was not until 1883, however, when the Canadian Pacific Railway was built through the region, that a cutting disclosed copper pyrites at what was afterward known as the Murray mine. Other discoveries soon followed at what became the Lady Macdonald, Evans, Copper Cliff, Stobie, and Blezard mines; in 1886 the vast Creighton deposit was rediscovered, and other discoveries followed. During the early years the ores were exploited for their copper content alone, but about 1889 the discovery by James Riley of nickel steel gave an impetus to the production of nickel.

The first important mining was done in 1886 at the Copper Cliff by the newly formed Canadian Copper Co., which also opened up the Stobie and Evans mines. In 1899 the Evans was closed down, and 2 years later the Stobie ceased working after having yielded 400,000 tons of ore. Several new mines were opened up by the company, including the No. 3, or Frood, which began operations in 1900, and the Creighton, which began to ship ore to the smelter in 1901. The Creighton deposit proved to be so immense and its ores so rich that the other mines were closed down one after another in consequence. In 1902, through a reorganization, the Canadian Copper Co. became subsidiary to the International Nickel Co., which combined several companies interested in the mining, smelting, and refining of nickel and copper. In 1900 the Mond Nickel Co. was formed to develop the Victoria mine, 3 miles northeast of Worthington. The same company later acquired some small deposits, such as the North Star and the Little Stobie, and in 1907 a larger deposit, the Garson, at the east end of the main nickel range. In 1910 it began to develop the Frood Extension, and a new smelter was commenced at Coniston. In 1913 it acquired the Levack mine. During the World War, when the demand for nickel for armaments increased, the British American Nickel Corporation was formed in order to insure a supply of nickel to the British Government. This corporation acquired the Murray mine at Copper Cliff, and a subsidiary company established a nickel-refining plant at Deschenes, Quebec. With the end of the war the nickel markets were cut in half, and in 1924 the company was liquidated, the Murray property being purchased by the International Nickel Co. In 1929 the International Nickel Co. absorbed the Mond Nickel Co. Immense reserves of copper-nickel ore were blocked out at depths of 2,000 and 3,000 feet at the Frood mine, and a large development scheme was begun. This included underground development, the erection of a new surface plant at the Frood mine, the construction of a concentrating plant, a new smelter, and a copper refinery at Copper Cliff, additions and improvements to the Coniston smelter, and a new surface plant at the Levack mine. The company at present has four mines equipped for large-scale operations—the Frood, Creighton, Levack, and Garson. It has for reserves three large mines—the Crean Hill, Murray, and Stobie—in addition to smaller mines, and is in a position to concentrate and smelt 8,000 tons of ore a day. Proved reserves at the end of December, 1932, aggregated 203,909,973 tons. The only other company operating at present on the copper-nickel ores in the area is the Falconbridge Nickel Mines, Ltd.

The copper-nickel ores occur along the outside border of the elliptical outcrop of the nickel irruptive; hence little interest was taken in prospecting in the interior of this area. In 1928, however, intensive development of a fault zone which was known to cross the region began, and large deposits of zinc-lead ore carrying some copper were discovered, but they are now idle owing to the low prices of the base metals.

Geology

All the rocks of the Sudbury area (fig. 4) are pre-Cambrian. The dominant structural feature is the Sudbury Basin, an agricultural area surrounded by a rocky rim. The basin, whose underlying rocks form a canoe-shaped syncline, has a maximum length in a northeast by east direction of 37 miles and a greatest width of 16 miles. The interior is a depressed, largely drift-covered area, but a series of broken sandstone ridges occurs in its central portion.

The rocks of the interior of the basin form the Whitewater series, whose members in ascending order are the Onaping volcanic fragmental rocks, the Onwatin slate, and the Chelmsford sandstone. The rocky rim surrounding the basin consists of a late pre-Cambrian intrusive rock injected between the base of the Whitewater series and the complex of earlier rocks upon which the series was deposited. This intrusive is known as the "nickel irruptive" and consists of norite in its lower part and micropegmatite in its upper part, separated by a narrow gradational zone. The pre-Whitewater complex embraces rocks of several ages. To the north and east of the basin they consist of pre-Huronian granite and granite gneiss. On the south the complex includes Keewatin volcanics and the overlying Sudbury series, also pre-Huronian, composed of quartzite, arkose, slate, etc., steeply tilted and intruded by basic rocks that are probably related to the nickel irruptive. On the south side of the basin are areas of late pre-Cambrian (Killarney) granite, which intrudes the rocks of the old complex and also the nickel irruptive. The intrusion of this granite apparently extended over a long period,

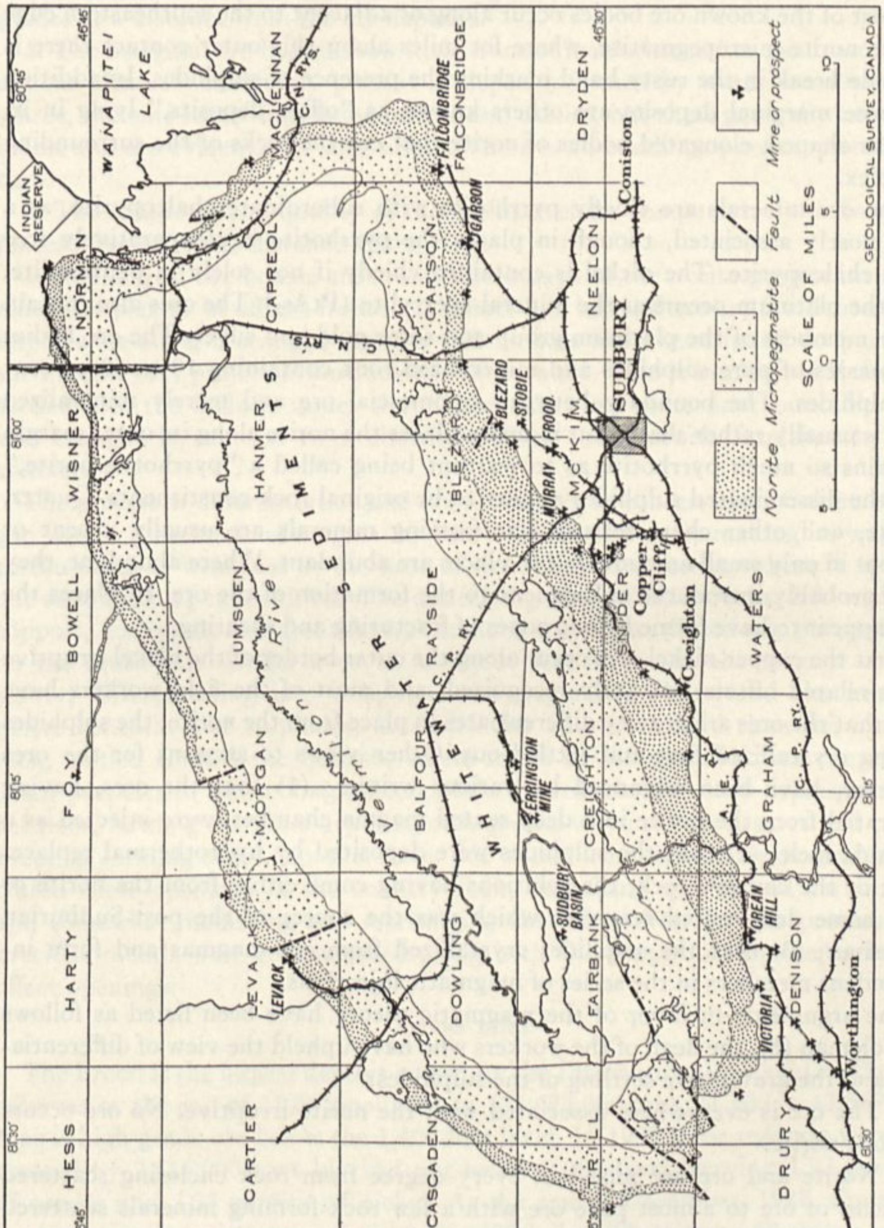


FIGURE 4—Geology of the Subury Basin, Ontario.

for though locally it cuts the nickel irruptive, elsewhere granite of this type is cut by the norite. The youngest rocks of the region are dikes of olivine diabase and trap, which cut the Killarney granite and the older rocks.

Most of the known ore bodies occur along or adjacent to the southeastern edge of the norite-micropegmatite, where for miles along this outer contact there is no wide break in the rusty band marking the presence of sulphides. In addition to these marginal deposits are others known as "offset deposits," lying in irregular-shaped, elongated bodies of norite that cut the rocks of the surrounding complex.

The ore minerals are chiefly pyrrhotite with subordinate chalcopyrite, as a rule closely associated, though in places the pyrrhotite is comparatively free from chalcopyrite. The nickel is contained chiefly if not solely in pentlandite, and the platinum occurs as the mineral sperrylite ($PtAs_2$). The ores also contain other members of the platinum group and some gold and silver. The ore bodies are masses of pure sulphides and mineralized rock containing 10 to 60 percent of sulphides. The boundary between commercial ore and merely mineralized rock is usually rather sharp, but in many places the norite along its outer margin contains so much pyrrhotite as to warrant being called a "pyrrhotite-norite," and the disseminated sulphides appear to be original rock constituents. Quartz, calcite, and other characteristic vein-forming minerals are usually absent or present in only small amounts but in places are abundant. Where abundant, they were probably introduced subsequent to the formation of the ore. In places the ores appear to have formed along zones of fracturing and shearing.

That the copper-nickel ores occur along the outer border of the nickel irruptive or in related offsets was early recognized, and most of the field workers have held that the ores are gravity differentiates in place from the norite, the sulphides having crystallized first and settled out. Other views to account for the ores however, have been advanced by various writers—(1) that the ores, having separated from the norite in a deep-seated magma chamber, were injected as a sulphide melt; (2) that the sulphides were deposited by hydrothermal replacement of the country rock, the solutions having come either from the norite or from some deep-seated reservoir which was the source of the post-Sudburian intrusives; (3) that the sulphides crystallized from ore magmas and form independent members in the series of magmatic injections.

The arguments in favor of the magmatic theory have been listed as follows by Coleman (8), the dean of the workers who have upheld the view of differentiation and the gravitative settling of the sulphides:

1. The ore is everywhere associated with the norite irruptive. No ore occurs without norite.

2. Norite and ore are mixed in every degree from rock enclosing scattered particles of ore to almost pure ore with a few rock-forming minerals scattered through it.

3. Except as included blocks or where influenced by direct contact with the nickel irruptive, the adjoining rock, whether granite, gneiss, greenstone, or graywacke, is never spotted with ore, nor does it have separate bodies of ore enclosed in it.

4. The freshest norite is generally close to the ore bodies, and much of it is speckled with ore. The best-preserved hypersthenes at the Murray and Creighton mines are in sections containing sulphides and not in specimens free from sulphides at a distance from the ore deposits.

5. The marginal ore bodies show little trace of hydrothermal or pneumatolytic action. Minerals commonly present in deposits formed by water are absent or scarce, the only exceptions being quartz and calcite, but these generally occur in seams and are evidently of later origin. There is no banding or concentric structure.

6. The character and quality of the ore masses are comparatively uniform at places a considerable distance apart.

7. The largest ore bodies are found where bays of the norite project into the older complex or in offsets from such funnel-like bays; there are few deposits of importance along a straight margin, and no ores have been found on parts of the margin that project inward instead of outward. This is intelligible if the ore settled into the hollows under the molten sheet but quite unaccountable if it was brought in solution from elsewhere along the channels furnished by the contact.

The process of differentiation and ore formation, as conceived by Coleman, began with a great mass of magma far below the earth's crust making its way up to the plane of weakness at the base of the Whitewater series, where it spread out as a sheet 1¼ miles thick. The underlying floor of older rocks, left without support, collapsed, and great faults extended in various directions, particularly on the south side. Under a cover of 10,000 feet of strata, the magma cooled slowly, differentiating into a lighter micropegmatite above and the heavier norite beneath. The sulphides, much heavier and more fluid than the molten rock, settled toward the bottom, where much of the material was caught as small particles in the cooling norite, while the rest escaped into depressions on the floor, forming marginal deposits, or found its way into the fissures and crush breccias, forming offset deposits. Later hot waters from the cooling magma penetrated these openings in the country rock, depositing quartz and carbonates and somewhat modifying and rearranging the offset ores. In this process the precious metals were concentrated along with the copper ore in the narrower offset openings.

Frood mine

The Frood is the largest deposit owned by the International Nickel Co. Proved reserves at the end of 1929 amounted to 134,673,000 tons, of which 43,562,000 tons is high-grade ore below the 1,400-foot level. In 1930 these reserves were increased by 2,416,000 tons blocked out below 2,000 feet, carrying 4.93 percent of copper and 3.53 percent of nickel. At the end of December, 1932, the total workings in the mine amounted to over 26 miles. There were 68 stopes, each capable of yielding an estimated production of 150 tons of ore a day.

The property is about 2½ miles north of the town of Sudbury, on lots 6 and 7, concession 6, McKim Township. The deposit is one of the offset type, occurring in an offset of norite roughly 2 miles long, running parallel to the border of the main norite mass, about 1 mile away. The offset, which is about 900 feet wide, intrudes graywacke and slates of the Sudbury series, commonly along the paths of older dikes or irregular intrusions that roughly follow the bedding of the sediments. The Frood ore body is at the southwest end of the offset zone, and another mine, the Stobie, at the northeast end. Between them there is some mineralized rock but little commercial ore.

The Frood deposit strikes northeast and dips about 60° NW. The ore is of the usual Sudbury type, consisting of a mixture of pyrrhotite (with a small percentage of pyrite), chalcopyrite, and pentlandite, with a little gold, silver, and plantinoids and varying amounts of rock matter. The pentlandite is generally more intimately associated with the pyrrhotite than with the chalcopyrite.

In the upper part of the ore body the sulphides are chiefly disseminated thickly through the rock. The ore improves with depth until at about 800 feet from the surface over half is sufficiently massive sulphide for direct smelting. Between depths of 800 and 1,100 feet the ore averages 2.1 percent of copper and 2.4 percent of nickel. In the next 300-foot block the gangue diminishes further, the copper content remains nearly the same, and the nickel increases to 2.7 percent. From 1,400 to 1,700 feet the grade continues to improve, and from 1,700 to 2,000 feet the combined copper and nickel content is over 5 percent. A little below the 2,000-foot level the percentage of copper noticeably increases, and at 2,800 feet it is 7 percent, with 3 percent of nickel. At 3,100 feet the ore assays 21 percent of copper and 1.7 percent of nickel, containing about 65 percent of chalcopyrite. The content of gold, silver, and platinoids increases also with depth disproportionately more than the increase in the base metals.

The Frood ores have been interpreted (9) as resulting from an original gravitative segregation of sulphides in the parent magma of the nickel irruptive before its intrusion, the formation of the Frood offset from this sulphide-enriched portion of the magma, and further differentiation after the intrusion of the offset.

Creighton mine

At the end of 1929 the International Nickel Co. estimated its reserves at the Creighton mine to be 5,503,000 tons. In 1930 this was increased by 2,648,000 tons found between vertical depths of 2,400 and 3,400 feet.

The Creighton is at the southwest corner of Snider Township, on lot 10, in the first concession, about 11 miles by road west of Sudbury. The deposit lies along the contact of norite to the northwest and granitoid gneiss to the southeast. The gneiss is commonly porphyritic, contains masses of greenstone, and is cut by finer-grained granite which is also younger than the norite. The youngest rocks are dikes of trap and olivine diabase, which cut all the others, including the ore zone.

The ore body dips about 45° N. and is about 1,000 feet long and about 180 feet wide on the surface. Between the fifth and sixth levels it abruptly narrows to a width of about 50 feet, which it maintains to the eighth level, but below that level it increases to widths greater than on the surface. The hanging wall of the deposit is norite, and the footwall granite.

Levack mine

At the end of 1929 the Levack mine, according to the annual report of the International Nickel Co., showed 19,062,000 tons of ore reserves. At the end of 1930 these had been increased by 137,000 tons.

The property is on lots 6 and 7, concession 2, Levack Township. It was the first deposit located on the north side of the basin, being taken up in 1889 by Rinaldo McConnell and James Stobie. It was later sold by these men to the Mond Nickel Co., and mining operations were begun in 1913.

The rocks are granite gneiss and the norite-micropegmatite. The gneiss contains many fine- to medium-grained greenstone inclusions and is cut by several fine-grained basic dikes. The contact of the norite with the granite gneiss is well exposed at the Big Levack, about 4 miles to the northeast, and shows that the norite is the younger. The deposit is marginal, occurring along the contact zone between the granite gneiss and the intrusive norite. The deposit dips about 45° SE., following the intrusive contact.

Garson mine

The ore reserves at the Garson mine at the end of 1929 were 3,193,000 tons, and in 1930 these were increased by 1,409,000 tons, according to the report of the International Nickel Co.

The property lies about 10 miles northeast of Sudbury, on lots 4 and 5, concession 3, Garson Township, on the southern nickel range. The deposit was discovered in 1891 and was first known as the Crydermann, after its locator. It later passed into the hands of the Mond Nickel Co., and a large tonnage of ore was mined.

The rocks on the property include greenstones, locally with amygdaloidal and ellipsoidal structure, quartzite and graywacke of the Sudbury series, and intrusive norite. The norite has been sheared and altered near the mine for 200 to 300 feet from the contact with the older rocks. It is cut by dikes of medium-grained granite as much as 30 feet in width. All these rocks and the ore body as well are cut by fresh diabase dikes.

In addition to the main ore body there are two smaller deposits known as the Northwest ore body and the No. 16. The main ore body is a marginal deposit near the contact of the norite with the older rocks, has a general northeast strike, and dips 53°–60° SE. It is 1,000 feet or more long and in places 100 feet or more wide. There is an unusual amount of quartz and somewhat less calcite intermingled with the sulphide. The northwest ore body strikes northwest and dips 80°–90° SW. It consists of three lenses pitching southeast. Ore body 16 is narrow, strikes southwest, and dips about 53°–60° SE.

Murray mine

The ore reserves proved at the Murray mine at the end of 1929 amounted to 22,490,000 tons.

This property, the first deposit to be discovered in the region, lies on lot 11, concession 5, McKim Township, about 3 miles northwest of the town of Sudbury. It was patented in 1884 to Thomas Murray, William Murray, Henry Abbott, and John Loughrin, who later sold it to H. H. Vivian & Co., of Swansea, Wales. Mining was begun in 1889 and carried on by the company until 1894. The mine was later sold to J. R. Booth, M. J. O'Brien, and associates, who, after blocking out a large tonnage of previously unknown ore, sold it to the British American Nickel Corporation. In 1924 the property was acquired by the International Nickel Co.

The oldest rocks of the vicinity are greenstones, apparently in part altered flow rocks. With them is associated a gabbro or closely related rock of obscure age, a coarse-grained feldspar porphyry, apparently a younger dike, and the norite, which contains inclusions of the gabbro. Later than the norite is a mass of granite about 3 miles long and 1 mile wide, which cuts to pieces the fine-grained greenstone and the gabbro with a network of dikes, some of which penetrate the norite for 100 to 200 feet. The youngest rock is olivine diabase, which cuts across all these rocks and also the ore bodies.

The deposit is marginal, lying along the contact of the norite and the older greenstone-granite complex. The ore body strikes northeast and dips 36° NW.; the norite forms the hanging wall and the older rocks the footwall. The mineralized zone is 5,000 feet long but not all of commercial grade. The average thickness normal to the strike and dip is 50 or 60 feet. About one-third of the material mined is waste. After hand sorting the product contains about 3 percent of nickel and copper combined.

Stobie mine

Ore reserves at the Stobie mine at the end of 1929 were estimated by the International Nickel Co. to be 13,712,000 tons.

The property is on lot 5, concession 1, Blezard Township, about a mile northeast of the Frood and in the same offset of norite. It was one of the earliest discoveries of the region and was worked extensively up to 1901, producing over 400,000 tons of ore that averaged 2.05 percent of nickel and 1.53 percent of copper. The rocks consist of green schist, hornblende porphyrite, graywacke, and crush conglomerate, as if the ore had been squeezed up along a crushed zone.

Crean Hill mine

Ore reserves at the Crean Hill mine at the end of 1929 amounted to 3,028,000 tons.

This property is on lot 5, concession 5, Denison Township, about 18 miles west of Sudbury. It was probably located by F. C. Crean, who obtained a grant of it in 1885. It passed into the possession of the Canadian Copper Co. but was not opened up until 1905. Its ores were found useful for mixing with those of the Creighton, being very siliceous and containing more copper than nickel, the reverse of the Creighton ore.

The deposit is marginal, occurring at the contact of the norite with an older complex of greenstones and small masses of quartzites and graywackes belonging to the Sudbury series. The ore and older rocks are cut by a dike of trap and younger dikes of olivine diabase. Dikes and irregular masses of granite cut the greenstone and the norite.

Falconbridge Nickel Mines, Ltd.

The Falconbridge Nickel Mines, Ltd., is essentially a producer of nickel but also maintains a steady output of copper, which has been marketed in Europe. Its property consists of 7,960 acres in the Sudbury region, mainly a group of claims in the western part of Falconbridge Township, with a small area in the eastern extremity of Garson Township. It lies at the southeast corner of the nickel irruptive belt, the contact between the norite and the older complex crossing the property for 16,570 feet. Development work was begun in September, 1928. This has consisted in diamond drilling, the sinking of two shafts, and horizontal work carried out on the 225-, 350-, and 1,000-foot levels. At the end of 1932 ore reserves averaging 2.25 percent of nickel and 0.93 percent of copper were estimated to be over 2,900,000 tons. The company's smelter, 2,000 feet southeast of the mine, has a capacity of about 450 tons a day. Matte carrying around 82 percent of combined nickel and copper metals is shipped to the company's refinery in Norway. In 1932 the ore smelted amounted to 123,306 tons and the matte produced to 4,947.6 tons.

Errington mine

The Errington mine is in the interior of the Sudbury Basin, in Creighton and Balfour Townships. It lies on a major fault zone, which extends along the southern margin of the basin. Coleman's map of the Sudbury Basin (7) suggests a fault offsetting the nickel irruptive near Cameron Lake, at the western extremity of the basin, and in 1921 C. H. Hitchcock suggested that this fault might cross the entire basin and be mineralized. Sulphides had been known at several places in this region and in 1924 were encountered by a diamond-drill hole put down in search of coal. Joseph Errington accordingly obtained options on a large area in this zone, which in July, 1925, were taken over by the Treadwell-Yukon Co. Diamond-drill holes were put down at 100-foot intervals, and after 48,000 feet had been drilled, sinking was begun in August, 1926, followed by drifting and crosscutting to explore the zone. A mill was erected which operated from 1928 to December, 1931, when the plant was closed down.

The property extends over 3 miles along the fault zone, which here follows closely the Whitson River. The country rock consists of slate and tuffs of the Whitewater series. The crushed zone may be several hundred feet wide, as indicated by drilling or underground exploration. It consists of black to gray altered slate and tuff, quartz, carbonate, and in places sulphides of iron, zinc, copper, and lead. The slate and tuff are highly carbonaceous, and the carbonate is so impregnated with carbon that it appears black. The quartz and carbonate are the earliest vein minerals, having replaced and included masses of slate and tuff. They form lenslike masses which occur repeatedly along and across the strike of the zone. Massive iron pyrite, locally nearly free from other sulphides, is the earliest and the most abundant sulphide. It has been in part replaced by sphalerite with galena, chalcopyrite, pyrite in cube form, and pyrrhotite. The sphalerite is in many places the host for other sulphides.

The property has been developed from three shafts. No. 1 is on a ridge of tuff near the southwestern border of the property. From it a crosscut was run on the 300-foot level to the fracture zone between tuff and slate, on which drifts were run both east and west. Prospecting crosscuts were run from the drifts at intervals, and by this work and diamond drilling several ore shoots were located. According to the annual report of the company for 1928 the Ollier stope at the end of the year had a proved horizontal cross section of 14,500 square feet, and the average assay of all samples of ore drawn from this stope was 0.033 ounce of gold and 2.08 ounces of silver to the ton, 1.08 percent of copper, 1.20 percent of lead, and 6.4 percent of zinc. The Larson stope had a proved area of 4,000 square feet in horizontal cross section, and the average assay of ore from this stope was 0.03 ounce of gold and 1.55 ounces of silver to the ton, 0.91 percent of copper, 1.1 percent of lead, and 5.4 percent of zinc. The Pit ore body proved to be but 120 feet long by 4 feet wide, although the average width on the outcrop is 20 feet. Samples of the ore from this stope averaged 0.045 ounce of gold and 2.15 ounces of silver to the ton, 1.05 percent of copper, and 6.9 percent of zinc. The Hargraft ore body, so far as known, had a length of 120 feet and a width of 15 feet. Shaft 1 was later sunk to 500 feet, and a crosscut was driven northwestward to the slate-tuff contact, which is considerably farther north than on the 300-foot level and at the surface. A drift on the fault zone on this level was run to the east to join the drift from shaft 2, and diamond drilling in 1930 intersected 10 feet of better ore than the same zone carried on the 300-foot level.

Shaft 2 is 3,600 feet east of shaft 1, and connection between the two was made on the 300-foot level. On the 500-foot level a northwest crosscut intersected four veins—the Romig, Christie, Rheaume, and North. The Romig, near the slate-tuff contact, shows a little sulphide; the others, in the slate, have shown commercial ore. According to the annual report for 1928, the east and west drifts on the Christie vein opened up an ore body 550 feet long without the easterly limit having been reached. The average explored width was 12 feet, and the average assay 0.038 ounce of gold and 2.03 ounces of silver to the ton, 0.60 percent of copper, 1.0 percent of lead, and 4.6 percent of zinc. The Rheaume vein, east and west drifts, disclosed ore over a length of 475 feet, with an average width of 12 feet; this ore still continued beyond the face of the east drift. The average assay from this ore body was 0.038 ounce of gold and 2.3 ounces of silver to the ton, 1.70 percent of copper, 1.0 percent of lead, and 3.5 percent of zinc. Three ore bodies with an aggregate length of 175 feet and an average width of 12 feet were found by the North vein drifts, and the average of all assays in this area was 0.038 ounce of gold and 2.3 ounces of silver to the ton, 0.36 percent of copper, 1.0 percent of lead, and 6.0 percent of zinc. The shaft was later deepened to 1,500 feet, with stations at 250-foot vertical intervals and crosscuts on the 1,500-foot level. Work was continued on the 500-foot level, and though no new ore bodies were encountered the dimensions of those already known was substantially increased. The horizontal cross section of all the ore bodies on this level is 100,000 square feet, or an ore occurrence of 10,000 tons to the vertical foot.

Shaft 3, near the east end of the property, was sunk to the 400-foot level, on which some exploratory work was done, but operations were discontinued here in 1928.

During 1928 the ore milled amounted to 39,092 tons, from which were recovered concentrates as follows: 354.4605 tons of lead, 2,744.61 tons of zinc, and 715.823 tons of copper. About 350 tons of lead concentrates containing 67.20 ounces of gold, 4,804.71 ounces of silver and 187,513 pounds of lead were shipped to Antwerp. Zinc concentrates amounting to 77 tons, containing 2.98 ounces of gold, 249.22 ounces of silver, and 71,052 pounds of zinc, were shipped to Trail, British Columbia, and Kellogg, Idaho. The copper concentrates were consigned to the American Smelting & Refining Co. and contained 121.51 ounces of gold, 7,045.33 ounces of silver, and 180,546 pounds of copper.

In 1929 the copper concentrates shipped amounted to 3,314.01 tons, averaging 15.21 percent of copper. Milling ceased on November 13, 1930, but shipments of concentrates during the year were 3,469.78 tons carrying 14.51 percent of copper.

Sudbury Basin Mines

The property of the Sudbury Basin Mines lies west of the Errington and comprises practically all the bed of Vermilion Lake and considerable territory on the south side. A band of highly sheared tuffs and slates striking N. 60°–70° E. and dipping steeply south crops out and shows gossan, quartz, and carbonates in the form of small stringers and lenses. It is apparently part of the main shear zone that passes through the property of the Treadwell Yukon Co. Most of the mineralized zone appears to underlie the lake and extends over a length of 5,000 feet, as indicated by drilling. One section, drilled at intervals of 100 feet, continues over a length of 1,500 feet and shows pyrite, sphalerite, chalcopyrite, galena, quartz, and carbonates. The general structural and mineralogic relations of the ore bodies are similar to those at the Errington mine (6). Assays of drill sections show gold, 40 to 50 cents a ton; silver, 1 to 3 ounces a ton; copper, up to 5.17 percent; zinc, up to 13.81 percent; and lead, up to 2.32 percent.

Northern Manitoba

Northern Manitoba contains one large producing copper property, the Flin Flon, operated by the Hudson Bay Mining & Smelting Co., Ltd.; another developed deposit of copper-zinc ore, the Sherritt-Gordon, now idle; and a third property, the Mandy, which during the World War produced over $2,000,000 worth of copper from high-grade chalcopyrite ore. Many other sulphide showings and gold-bearing quartz bodies have been discovered. The region is sometimes spoken of as "The Pas mineral belt," as it is reached from the town of The Pas, northern Manitoba. Active prospecting began here in 1913, when gold-bearing quartz was discovered on Amisk Lake, in northern Saskatchewan a few miles west of the Manitoba boundary. In 1914 prospectors working in the Wekusko Lake region, 100 miles farther east, also discovered gold-bearing quartz at that end of the belt. In 1915 the Flin Flon and Mandy copper-zinc sulphide bodies were located, and in 1916 other sulphide bodies were discovered near Athapapuskow Lake. In 1927 there were promising developments of copper-zinc ore at the Sherritt-Gordon, which was actively explored in 1928 and 1929. A concentrator was built in 1930 and began producing copper concentrates in March, 1931.

In 1927 the Hudson Bay Mining & Smelting Co. was organized to operate the Flin Flon deposit. In 1928 the Canadian National Railways built a branch line 87 miles to Flin Flon, and in 1929 a branch 42 miles from this line to Sherritt-Gordon.

The mineral belt lies near the southwestern margin of the Canadian Shield, where the Shield is overlapped by flat-lying Ordovician dolomite. The rocks of the belt are all of pre-Cambrian age and may be divided into two main groups—those of superficial origin and those of intrusive, deep-seated origin. The chief members of these two groups are listed below.

Formations in mineral belt of northern Manitoba

Formations of superficial origin

Missian sediments.	Graywacke, quartzite, arkose, conglomerate, and derived mica and hornblende schists.
Unconformity	
	Kisseynew sedimentary gneisses, including gneissic quartzite, quartz-mica-garnet gneiss, quartz-hornblende-plagioclase-garnet gneiss, and crystalline limestone.
Wekuskoan sediments and volcanics.	Wekusko-Kiski sediments and volcanics, including mica schist, garnet, staurolite, and cyanite gneisses, graywacke, arkose, conglomerate, iron formation, basalt, andesite, rhyolite, and chloritic and sericitic schists.
	Amisk volcanics and sediments, including basalt, andesite, rhyolite, agglomerate, tuff, cherty quartzite, slate, and chlorite and sericite schists.

Formations of deep-seated origin

Younger basic intrusives.	Olivine diabase.
Intrusive contact	
Post-Missian granitic and basic intrusives.	Hornblende and mica lamprophyre. Pegmatite and aplite. Granite. Quartz diorite and granodiorite. Pyroxenite, peridotite, gabbro, and quartz gabbro.
Older (?) intrusives.	Granite gneiss, syenite gneiss, and quartz porphyry.

The Missian sediments, recognized in several areas, are clearly separated from the Wekuskoan group by a great unconformity. They are generally much less metamorphosed and carry numerous boulders of the older complex. The age of the intrusive rocks relative to each other and to the two groups of superficial rocks is not everywhere definitely known. Both the Wekuskoan and the Missian sediments carry boulders of granite, but on the other hand the Missian sediments are cut by granite and by basic intrusives. Elsewhere granitic gneisses are cut by pyroxenite and gabbro and these in turn by dikes of granite and pegmatite, suggesting that granites of two ages are present, but it is not yet known whether the older granites are of Wekuskoan age, or older or younger than the Wekuskoan.

Flin Flon mine

History.—The Flin Flon ore body crosses the boundary between Manitoba and Saskatchewan, but most of it lies in Manitoba. It was located in 1915 by a party composed of Messrs. Creighton, Mosher, Dion, and associates. The discovery was a zone of iron-stained rock near the shore of Flin Flon Lake. Some trenching was done, but the outcrops were so completely leached that little could be learned of the ore from surface work. J. E. Hammel interested financiers in New York and Boston in the discovery, and in March, 1916, diamond drilling began. In 4 months about 6,000 feet was drilled, and then work ceased. In 1917 Toronto interests agreed to continue drilling, and by July, 1918, 44 holes aggregating 25,664 feet had been drilled. This work blocked out the ore body and showed that it extends 900 feet below the surface. In 1920 an option was taken on the property by New York and Canadian interests, and underground work commenced. Two shafts were sunk on the ore body, 500 feet apart, and enough horizontal work was done to confirm the results of drilling. In 1921 the Mining Corporation of Canada bought a controlling interest in the property and explored for more ore deposits and for siliceous flux material in the surrounding area. In 1925 the Whitney interests exhaustively examined the deposit, and in November, 1927, the Hudson Bay Mining & Smelting Co. was organized to develop it. In 1928 the Canadian National Railways built a branch line to the property. In 1928 and 1929 a hydroelectric plant of 44,000-horsepower capacity was built at Island Falls, on the Churchill River, 65 miles north of the deposit, and in 1930 a concentrating and metallurgical plant to treat 3,000 tons of ore a day was completed. In the autumn of 1930 the first large shipment of copper was made. The deposit is now being mined from a large open pit and also from underground stopes. In 1931 the concentrator treated 1,090,596 tons of ore assaying 0.0893 ounce of gold and 1.094 ounces of silver to the ton, 1.939 percent of copper, and 3.823 percent of zinc. Metals sold in 1931 returned $5,401,312.65, which covered all operating expenses but not the interest on bonds and depreciation. In 1932 the capacity of the mill was increased to 4,000 tons a day, and a maximum of about 4,300 tons was reached. The company's copper smelter is producing at the rate of about 21,000 tons of blister copper a year.

Geology.—The rocks associated with the deposit are volcanic and intrusive. The volcanic rocks consist of basic flows, "greenstones," in places ellipsoidal and amygdaloidal, with some associated tuffs and coarser fragmental rocks, and include massive to highly schistose varieties. The intrusive rocks consist of hornblende lamprophyre and a younger quartz porphyry which is related to the granites of the surrounding region.

The ore body (see figs. 5–7) lies in the volcanic rocks, strikes N. 30° W., and dips 60°–70° NE. Drilling shows that it rakes at a low angle to the south. Dikes of quartz porphyry were encountered in drilling, and one dike forms the hanging wall of the deposit for some distance. The ore body is a fairly regular lens, tapering gradually to the northeast and ending rather bluntly to the southwest, where it breaks into two parts with minor mineralized zones. The ore body is 2,593 feet long on the surface and over 1,000 feet long at a depth of 900 feet. Its greatest thickness is 400 feet, but this includes some intercalated bands of unmineralized greenstone, the largest of which forms the ridge along the strike of the ore body between the two original shafts. At a depth of 900 feet the ore body has narrowed to 35 feet. There is over 18,000,000 tons of ore, without including the unmineralized horses of country rock or the ore below the 900-foot level.

The principal minerals are pyrite, sphalerite, and chalcopyrite, with some gold and silver. Arsenopyrite, galena, and magnetite have also been recorded, and a little native copper has been found near the surface. Quartz occurs in places between grains of pyrite and as veinlets traversing the sulphides; calcite is rarely associated with it.

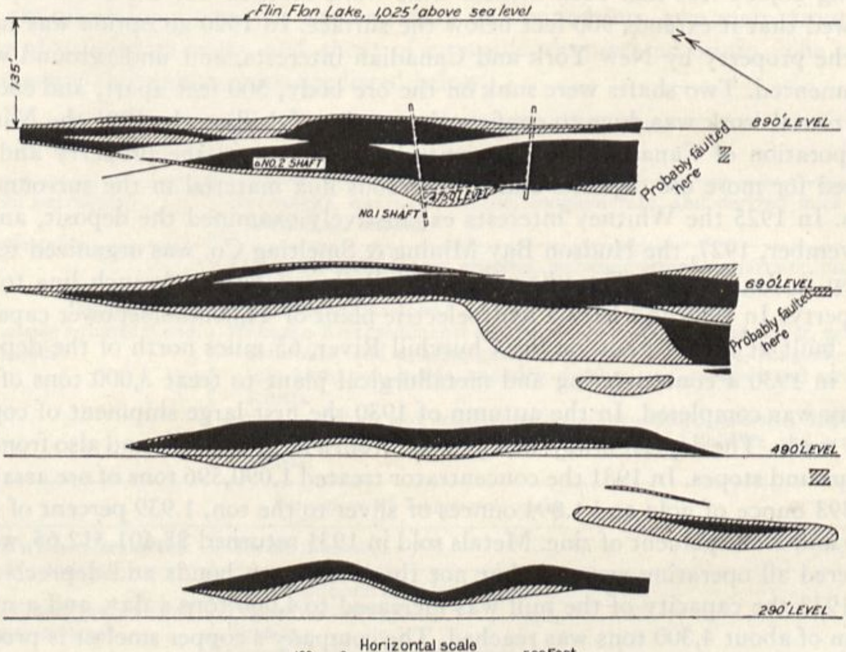


FIGURE 5.—Plans of Flin Flon ore body, Manitoba, at levels 200 feet apart. Sulphide ore shown by solid black; disseminated ore by ruling. (After Canada Geol. Survey Econ. Geology ser., no. 8.)

The ore consists of two fairly distinct varieties, the solid sulphide and the disseminated ore. The massive sulphide is made up chiefly of very fine grained pale-colored pyrite, containing sphalerite, chalcopyrite, rare fragments of schist, and some quartz and calcite. In places the pyrite is distinctly banded by the sphalerite and chalcopyrite. The sphalerite is the dark iron-bearing variety marmatite. The disseminated ore consists of country rock, chiefly chlorite schist, impregnated with sulphides. The solid sulphide variety forms the core of the lens, though in places it extends to the hanging wall, whereas the disseminated ore is largely in a zone along the footwall. Disseminated ore is also found on the hanging wall in the upper part of the deposit, but the copper content is here

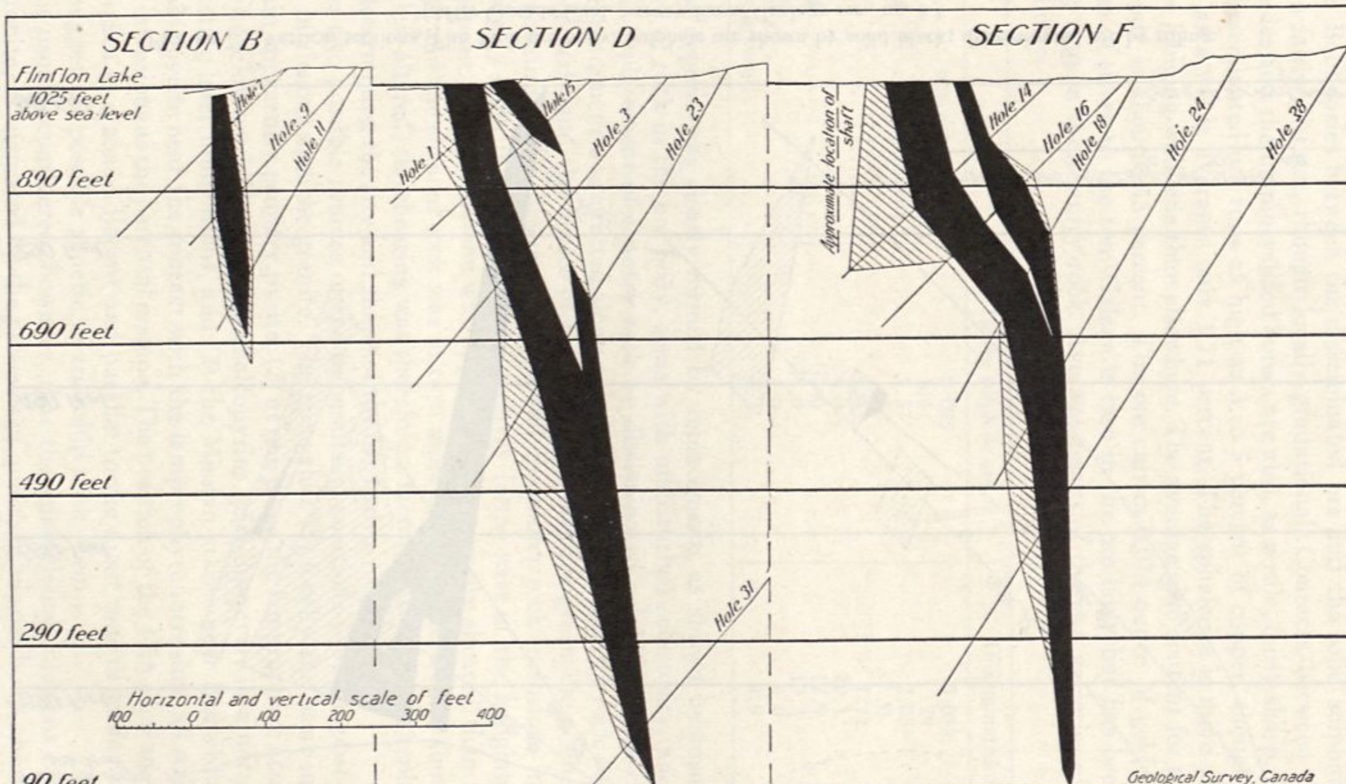


FIGURE 6.—Vertical sections, Flin Flon ore body. Sulphide ore shown by solid black; disseminated ore by ruling. (After Canada Geol. Survey Econ. Geology ser., no. 8.)

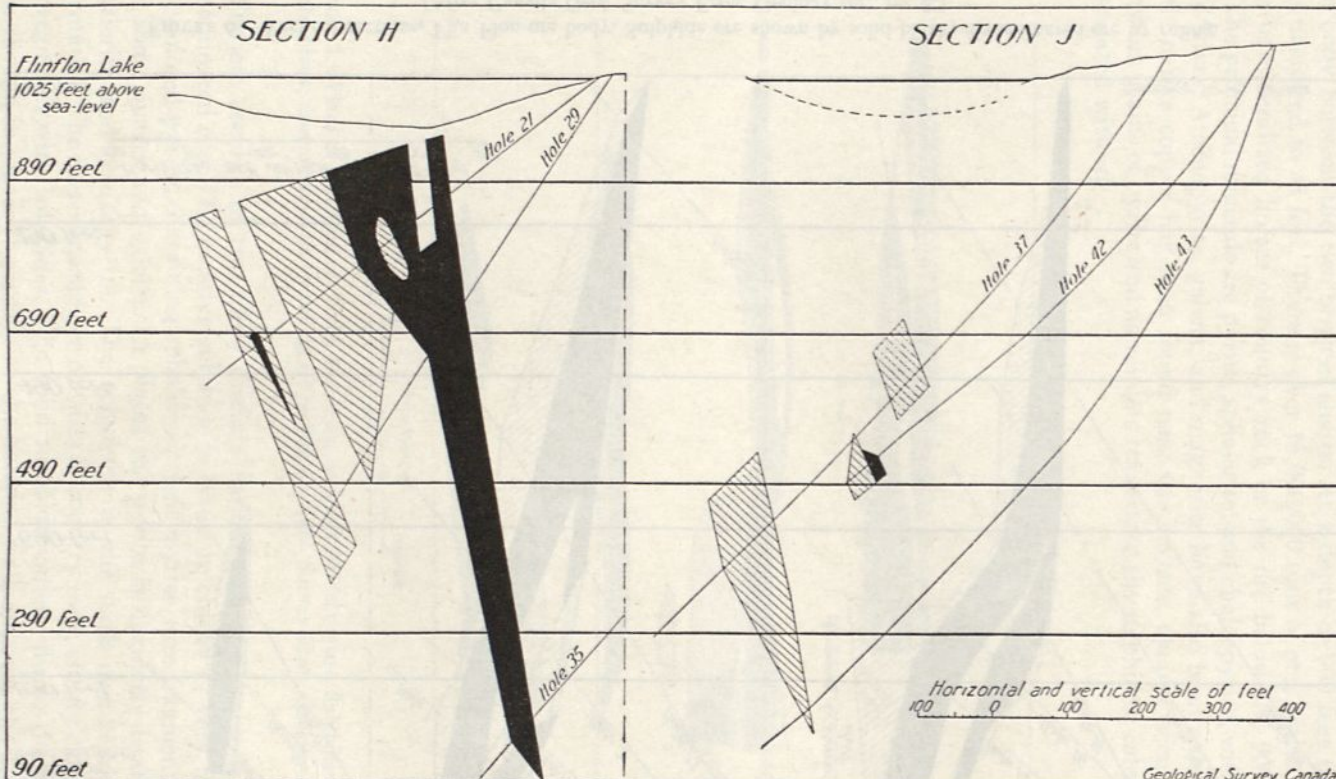


FIGURE 7.—Vertical sections, Flin Flon ore body. Sulphide ore shown by solid black; disseminated ore by ruling. (After Canada Geol. Survey Econ. Geology ser., no. 8.)

less than in the disseminated ore on the footwall. In places, in both plan and section, disseminated ore forms a zone on each side of the central massive sulphide. Boundaries between the disseminated ore and the solid sulphide are as a rule fairly distinct, though locally gradational. Contacts between the solid sulphides and the unmineralized horses are also, as a rule, fairly sharp. In places the disseminated ore runs as high as 3 to 5 percent of copper, though the ore body as a whole averages only 1.71 percent. The sphalerite is more abundant on the hanging-wall side than elsewhere. The average zinc content for the whole ore body is about 3.45 percent. The ore carries 0.074 ounce of gold and 1.06 ounces of silver to the ton. Galena is rare in the ore body but has been found lining vugs in the country rock. Average assays of the two varieties of ore are as follows:

	Heavy sulphide ore	Disseminated ore
Gold........ounces to the ton..	0.095	0.018
Silver..................do....	1.4	.29
Copper.............percent..	1.57	2.05
Lead..................do....	.5	.0
Zinc..................do....	4.4	1.12
Silica.................do....	4.0	29.1
Sulphur..............do....	37.0	12.9
Iron..................do....	35.0	19.3
Magnesia.............do....	1.0	8.0
Specific gravity..............	4.2	2.9

The deposit was clearly formed by replacement, as shown by unsupported masses of rock in the ore body, some with undisturbed schistosity, and by the partial replacement of country rock by disseminated sulphides. It is clear also that replacement was effected along a shear zone, for the country rock away from the ore body and the horses of rock in it are massive greenstone, whereas the rock containing the disseminated ore and the minor rock inclusions in the ore are largely chlorite schist. Quartz porphyry forms part of the hanging wall of the deposit. The greenstone was apparently more easily sheared than the porphyry, and the sheared rock was in turn more easily replaced than those which were less altered; the shearing was therefore a factor controlling the replacement and determining the size and shape of the ore body.

The two possible sources of the mineralizing solutions were the post-Missian basic intrusions and the granite. The facts that (1) locally the basic intrusives contain apparently primary pyrite, (2) at one place the lamprophyre across from the Flin Flon ore body contains chalcopyrite (this, however, in a narrow zone suggesting later infiltration), and (3) the Missian arkose near Beaverdam Lake contains pyrite near the contact with the lamprophyre intrusion, all suggest the basic intrusions as the parental magma. The position of the Flin Flon and Mandy ore bodies in a zone adjacent and parallel to the main zone of basic intrusives also suggests a possible genetic relationship with them.

It is usually considered, however, that the mineralizing solutions came from the granite, as suggested by the presence of quartz in the ore body, showing that the mineralizing solutions were siliceous and hence more likely to have come from a granite magma than from a basic one. Quartz is found interstitially to pyrite and as small stringers cutting the ore. The presence of gold and silver in the ore also suggests an origin from the granite, as the gold-bearing quartz veins of the region are clearly related to the granite batholiths. Again, certain sulphide bodies occur where no basic intrusives of post-Missian age are found, and if these originated in the adjacent granites, it is probable that the Flin Flon ore body did also.

The ore-bearing solutions were hot. The wall rock near the sulphide zone is highly sericitic: some of it consists only of sericite, quartz, and pyrite. Irregular masses of talc occur in the chlorite schist and in the sericite schist of the footwall. The ore deposition, therefore, was the result of the replacement of a sheared zone in volcanic rocks by solutions of intermediate to high temperatures given off from the granite intrusives. The shearing took place during the folding that accompanied the granite intrusion, and the replacement occurred toward the end of the period of intrusion. The solid sulphide pyritic ore was formed first; the later solutions were relatively richer in copper and formed the disseminated ore on both sides of the solid sulphide mass.

Mandy mine

History.—The Mandy mine is about 3½ miles southeast of Flin Flon on a small peninsula on the northwest arm of Schist Lake. The property was staked in the autumn of 1915 by two prospectors, Messrs. Reynolds and Jackson. J. E. Spurr, geologist of the Tonopah Mining Co., immediately obtained an option on the discovery for his company. In the following January a preliminary examination was made, and in the spring a diamond drill was installed, the first to be used in northern Manitoba. By midsummer the entire ore body had been blocked out and the tenor ascertained. It was found that there was 25,000 tons of massive chalcopyrite averaging about 20 percent of copper and $5 a ton in gold and silver and about 180,000 tons of lower-grade ore consisting of mixed copper, iron, and zinc sulphides, with some gold and silver.

The ore body was too small to justify erecting a smelter on the property. Owing to the war price of 26 cents a pound for copper, however, mining operations were begun immediately. The main difficulty was that of transportation. Mining machinery had to be taken in, and the ore sent to Trail, British Columbia, to be smelted. Operations began in January, 1916. Buildings and stables were erected, and 80 miles of winter road was made. In 3 months mining machinery was taken in from The Pas, and 3,800 tons of ore was mined from the surface and teamed to Sturgeon Landing, which was connected with The Pas by river steamer.

A shaft was begun in the spring, and during the succeeding winter stoping was started from the 100-foot level. The ore mined, 7,500 tons, was transported by barges down Schist Lake, hauled to Sturgeon Landing, and thence shipped by water to The Pas. For transport on Schist Lake four barges and two steamers were built, and considerable work was done on Schist Creek in making a channel and dam in order to get a passage to Lake Athapapuskow. In the third year mining was done on the 200-foot level. About 8,000 tons of ore was teamed 7 miles and piled near the outlet of Schist Lake, whence it was hauled out the following year, and 5,000 tons was teamed from the mine to Sturgeon Landing. The average load of a single team for the whole winter was 6½ tons, and the cost of the transportation was 37½ cents a ton-mile. In 1917 and 1918 the Ross Navigation Co., of The Pas, transported the ore from Sturgeon Landing to The Pas, but in 1919 the Mandy Mining Co. took over the Ross boats and handled all the transportation itself. In all four steamers and seven barges were employed between Sturgeon Landing and The Pas, a distance by water of 120 miles. At The Pas the ore was loaded on freight cars and shipped 1,200 miles to Trail. The last shipment was made in August, 1920. Mining operations lasted for 3 years and transportation for 4 years. The time from the mining of the ore until the delivery at the smelter was 1 year. Altogether 25,000 tons of high-grade ore was thus handled, yielding 9,866,328 pounds of copper, valued at $2,039,943. In 1930 the property was again under development, but no production was made.

Geology.—The rocks on the peninsula on which the Mandy ore body occurs are greenstone, pyroclastic rocks, and chlorite schists. The ore lens is in a band of schist with massive greenstone on each side. The lens is 225 feet long and has a maximum width of 40 feet. It is of irregular shape and lies parallel to the strike of the schist and greenstone bands. At each end a narrow sulphide vein branches off along the strike of the schist, suggesting that the ore body replaces a drag fold in the volcanic rocks. The lens dips 75°–80° E. and pitches steeply south. Its central part consisted of high-grade chalcopyrite surrounded by sphalerite and pyrite. This central lens of chalcopyrite was 12 feet in maximum width on the surface and 100 feet long. On the 100-foot level it widened to over 18 feet. It varies slightly in strike from the sulphide deposit as a whole. The zones of the various sulphides are gradational. The sphalerite zone is well banded; the pyrite zone roughly banded. The chalcopyrite lens averaged, copper, 19 percent; gold, 0.10 ounce a ton; silver, 2½ ounces a ton.

The deposit was strongly glaciated, and the weathered products formed in preglacial time were all removed, so that practically fresh sulphides were exposed at the surface beneath the covering of moss, though negligible quantities of chalcanthite and other secondary copper minerals were locally present.

The sulphide paragenesis was pyrite and arsenopyrite, sphalerite and chalcopyrite, galena. Pyrite, the most abundant mineral, predominates in the outer zone of the ore body. The pyrite zone grades from the massive sulphide type into country rock impregnated with sulphides. It contains also chalcopyrite and sphalerite and locally is roughly banded, owing to the parallel arrangement of zones of pyrite, zones of pyrite with chalcopyrite, and zones of pyrite with sphalerite. The pyrite occurs as cubes and irregular grains, which are in places fractured, and the fractures filled with later minerals. Arsenopyrite is present as small grains throughout the ore body and was apparently deposited with the pyrite.

Chalcopyrite, forming the central part of the lens, in polished sections shows inclusions of country rock, which are impregnated with pyrite and in places broken and cemented by sphalerite and chalcopyrite. The chalcopyrite and sphalerite were apparently contemporaneous, are intimately intergrown in many places, and generally form a matrix cementing pyrite grains, filling fractures in pyrite, or less commonly replacing pyrite. The chalcopyrite is massive and unusually pale in color on fresh fracture. An analysis of the purest ore that could be selected gave 28.96 percent of copper.

The sphalerite is massive and dark-colored, with a metallic luster quite different from that of ordinary blackjack, and shows no cleavage or crystal faces. Locally chalcopyrite and sphalerite form well-banded ore, but chalcopyrite is present in the sphalerite bands and sphalerite in the chalcopyrite bands, with no evidence of any age difference between them. These bands range from some a quarter of an inch or so wide to extremely narrow bands. The purest sphalerite ore that could be selected yielded the following analysis: Zinc, 46.21 percent; copper, 1.70 percent; iron, 12.80 percent; gold 0.07 ounce to the ton; silver, 0.85 ounce to the ton. Some of this iron may be in pyrite and chalcopyrite, but most of it is certainly contained in the sphalerite. Galena is found in small quantities in the chalcopyrite and sphalerite.

The gangue includes quartz and carbonates, filling fractures in the pyrite and between pyrite grains. The quartz is later than the pyrite but is mostly earlier than or contemporaneous with the chalcopyrite and sphalerite. The carbonates are mostly later than the sulphides. The country rock is chlorite schist, composed of secondary minerals; at the wall it is in places a fissile sericite schist.

The Mandy ore body was apparently of similar origin to that of Flin Flon. Solutions, probably derived from the granite, deposited pyrite in a shear zone, replacing the schistose rock. Movement took place during the period of deposition, and later the solutions became relatively richer in copper and zinc. Toward the end of the period of mineralization chalcopyrite deposition was dominant, and the central lens of chalcopyrite and the chalcopyrite veins cutting the sphalerite zone were formed.

The property is now idle, but a return of high prices for copper and zinc might render available the remaining lower-grade ore, which could be treated at the Flin Flon plant.

Sherritt-Gordon mine

Location.—The Sherritt-Gordon deposit lies about 100 miles north of The Pas and 40 miles northeast of Flin Flon. It is at the southeast end of a narrow lake lying east of Kississing Lake. Kississing is a large lake tributary to the Churchill River on the main canoe route from Cumberland House, on the Saskatchewan River, by way of Lake Athapapuskow to the Churchill River. The railway to the property branches off from the line between The Pas and Flin Flon at Cranberry Portage.

History.—The deposit was discovered by Philip Sherlett, an Indian trapper, who staked the first claims in 1922. Other persons located adjacent ground, and about 1¼ miles southeast of Sherlett's discovery Carl Sherritt and Richard Madole made a second discovery and staked several claims. As prior stakings ran out, these two added to their group, and finally, in 1925, Sherlett's claims having lapsed, they restaked them, thus acquiring both discoveries. In September, 1925, an option on the property was taken by J. P. Gordon, who at once reoptioned it to Alex. Faskin and E. P. Earle. Drilling was begun, two ore shoots were indicated, and it was estimated that about 450,000 tons of copper ore was proved. The Earle-Faskin option lapsed in September, 1926, and between that date and July, 1927, several companies optioned the property but did little additional work. In the summer of 1927 the Sherritt-Gordon Co. took over the property and began development. Adjacent claims were added, and the property now consists of 165 claims.

In the summer of 1927 the sulphide zone was trenched at all points along its strike where the drift mantle was thin. In January, 1928, diamond drilling was begun, and by the autumn of that year 64 holes aggregating 27,360 feet had been drilled. In February, 1928, shaft 1 was begun on the East ore shoot, and in March, shaft 2, $1\frac{1}{4}$ miles away, was commenced on the West or the original discovery. Diesel-driven compressors were used. Early in 1929 shaft 3, 2 miles northwest of shaft 1, was begun to explore the northwest end of the deposit. This is a five-compartment shaft, inclined 51°, following the footwall gneiss. The main haulage level from this shaft is 500 feet down the dip and was planned as the outlet for three-quarters of the ore to be milled during the first 10 years of work. By August, 1930, shaft 1 was 370 feet deep, and drifting had been completed on the 125- and 250-foot levels. Shaft 2 was sunk to a depth of 680 feet; stations were cut at 200, 350, 500, and 650 feet, and the first, second, and third levels were driven 550 feet each way from the shaft. In addition drilling was continued to prospect the ore zone further. During 1929 a 10-ton pilot mill was built, and a complete method of concentrating the ore was evolved. The concentrating plant was built at shaft 3. In March, 1931, one unit of the mill was ready for operation, and by May the rated capacity of the unit, 600 tons in 24 hours, was being milled. Milling continued until June 20, 1932, when the plant was closed down. The concentrates were shipped to the Flin Flon smelter, and the blister copper to the Copper Cliff refinery. Electric power was purchased from the Island Falls plant of the Hudson Bay Mining & Smelting Co. The ore mined was low in zinc, and no attempt was made to save this metal. The concentrator design, however, provides for installing the necessary equipment whenever a market develops for the zinc.

Geology.—The rocks in the region consist of sediments intruded by granite and pegmatite. The sediments are metamorphosed and constitute the Kisseynew sedimentary gneisses. The sediments were originally sandstones, clayey and limy sandstone, clayey arkose, and limestone. They were intimately invaded by granitic intrusives. A widespread variety is a gray medium-grained quartz-mica-garnet gneiss. Some bands are quartzites. Interbanded with the lighter-colored acidic gneisses are dark-colored basic rocks consisting of black hornblende-plagioclase-garnet gneiss and quartz-calcite-hornblende gneiss.

The Kisseynew gneisses have been thrown into open folds and along certain zones into close overturned folds. On the Sherritt-Gordon property the structure is that of an overturned anticline, both limbs dipping northeast. The dip of both bedding and foliation of the gneisses ranges from 35° to 60° except near the east end of the deposit, where the strata stand vertical or dip steeply south and southeast. Many small drag folds are developed along incompetent beds, particularly along a zone at the tip of the gneissic quartzite horizon about 750 feet south of the ore bodies.

The ore deposits lie in the gneisses, alongside of or just within a wide band of thick-bedded gneissic quartzite. They follow the structural planes of the sediments. The footwall is gneissic quartzite; the hanging wall is hornblende-bearing garnet gneiss with intercalated beds of gray acidic gneiss and thin beds and lenses of crystalline limestone. The ore bodies are tabular masses of gneiss carrying pyrrhotite, pyrite, chalcopyrite, and sphalerite in varying proportions. Here and there replacement of the gneiss by the sulphides has been almost complete; elsewhere only slight. Calcite is abundant locally in the ore, suggesting that thin beds of limestone were originally present among the quartzose beds along the sulphide-bearing zone. Gold and silver are present in small quantities. Other metals such as cadmium and lead occur in minute amounts but can be detected only by analysis.

The East ore body is 4,200 feet long and averages 15.2 feet in width; the West ore body is 5,200 feet long and averages 15.5 feet in width. Diamond drilling has revealed some mineralized rock in the section between the two main deposits, but not much ore has been proved there or beyond the end of the two deposits. The East ore body was estimated from the drilling to contain 866,175 tons of ore carrying 2.14 percent of copper; the West ore body was estimated to contain 3,271,900 tons of 2.91 percent copper ore with a lower-grade section of 1,116,500 tons carrying 1.40 percent of copper. The average zinc content of these deposits is respectively 5.78, 2.76, and 0.80 percent. In 1931 the low-grade section of the West ore body was opened up by a drift for one-third of its length, and the copper content for this portion averaged 2.5 percent. Stoped ore in the shaft block of the West ore body in 1930 averaged 3.63 percent, which was also better than the original estimates. The average assay of ore treated in 1931 was copper 3.735 percent, gold 0.026 ounce to the ton, silver 0.754 ounce to the ton. For the month of May, 1932, the property produced copper at a price of 5½ cents a pound, refined. Should copper stabilize at 8 cents or more, the property would probably be reopened.

Arctic Canada

Native copper is known in Arctic Canada on the Coppermine River, which drains an area between Great Bear Lake and Coronation Gulf, and on the islands of Bathurst Inlet, about 200 miles to the east. It has also been reported to occur about 40 miles northeast of the head of Prince Albert Sound, on the west coast of Victoria Island, and at a point about 60 miles east of Bathurst Inlet.

The presence of native copper in the Coppermine River region was known from early days from reports and specimens brought in by Indians to the Hudson's Bay Co.'s post at Churchill, and in 1769 Governor Norton, of Fort Churchill, sent Samuel Hearne to find the mine from which the specimens had been obtained. On his third attempt Hearne reached the Coppermine River in 1771, but owing to his lack of knowledge of minerals and rocks his report is very vague.

In 1821 Sir John Franklin descended the Coppermine River to the Arctic coast. He reported native copper occurring as float along the river, and Richardson, one of his assistants, noted the similarity of the rocks to those of the Keweenawan of Michigan. In 1825–26 Dease and Simpson, of the Hudson's Bay Co., wintered on Great Bear Lake and in the spring descended the Coppermine River to its mouth and then followed the coast eastward. They noted the native copper on the Coppermine River and on Barry Island, in Bathurst Inlet, and reported red sandstone on Victoria Island. Other explorers who passed along the Coppermine also noted copper float; of these, August Sandberg, a Swedish chemist and geologist who accompanied George M. Douglas and Lionel Douglas to the Coppermine in 1911–12, has given us the most detail about the occurrences. The southern party of the Canadian Arctic Expedition spent from August, 1914, to July, 1916, in this general region, and the report of its geologist, J. J. O'Neill, is given in volume 11 of the report of the expedition. More recently, in 1929 and 1930, prospecting and exploration has been carried out by Dominion Explorers, Ltd., and by the Northern Aerial Minerals Exploration Co.

The oldest rocks exposed in place are pre-Cambrian granite, but these contain inclusions of still older schists, and it is probable that older formations may occur in neighboring districts. Resting on the granite in places is the Epworth dolomite, which has a thin basal conglomerate and grades up through arkose into a cherty dolomite. A younger formation, the Kanuyak, at one place lies with structural unconformity on the Epworth beds. It consists of fine-grained calcareous tuffs and tuff-conglomerates. A third formation, the Goulburn quartzite, in the Bathurst Inlet region, contains rounded fragments apparently of the Epworth dolomite and the Kanuyak formation and is therefore considered younger than these formations. The next younger rocks are those of the Coppermine River series, which contains all the native copper of the region. It consists predominantly of amygdaloidal lavas with some conglomerate in the lower part, passing upward into a great series of interbedded shales and sandstones. A conservative estimate for the total thickness of the series is 48,000 feet. Large dikes and sills of diabase cut the Coppermine and older formations; they are prominent throughout the pre-Cambrian areas and have been assumed to be of pre-Cambrian age and to belong to one period. Paleozoic sediments occur on the mainland northwest of the mouth of the Coppermine River, on Victoria Island, and on the islands of Coronation Gulf.

Lower Coppermine River

The Coppermine River about 40 miles from its mouth cuts through a belt of high land about 15 miles wide known as the Copper Mountains. These attain an altitude of only 1,200 to 1,500 feet and present the appearance of a plateau, interrupted by a series of mutilated ridges facing south, with vertical cliffs of different heights, and sloping gently toward the north. North of the mountains the country is a plain of low relief traversed by narrow basalt ridges having the same general trend as the Copper Mountains.

The Copper Mountains are composed of basaltic flows with which are interstratified several beds of reddish conglomerate, apparently most numerous in the upper part of the series. The general strike is easterly, and the dip averages less than 12° N. The flows vary in thickness and usually present two parts, an upper, narrower amygdaloidal portion grading down into a compact nonamygdaloidal portion. The amygdules consist of calcite, zeolites, epidote, chlorite, quartz, and native copper. In places small fissures, forming a network of seams, are filled with calcite; some of them contain chalcocite. A sandy shale overlies the basalts to the north and is succeeded by reddish-brown sandstone, which continues north for 30 miles to Bloody Falls. At four horizons in the sandstone are basalt flows, none more than 100 feet thick.

The copper occurs principally in the amygdaloidal portions of the flows of the Copper Mountains, some of which carry considerable percentages of the metal. In places also the matrix of the conglomerate has been replaced by copper. Numerous large masses of copper occur in the drift immediately north of the copper-bearing rocks west of the Coppermine River, so that it is at least possible that the district contains workable and even rich deposits.

Both the Dominion Explorers, Ltd., and the Northern Aerial Minerals Exploration Co. have discovered copper sulphide deposits. The Dominion Explorers made some nine discoveries. Two are fissure veins of calcite and quartz in basalt and contain much chalcocite and bornite. Three discoveries of quartz veins carrying bornite, chalcocite, and chalcopyrite were made. One at Hunter Bay, at the east end of Great Bear Lake, appears from the float and from the moderate amount of trenching done to be of considerable size. On islands in Hunter Bay a large body of altered porphyry mineralized with chalcopyrite, chalcocite, and bornite to an indicated extent of 2.5 percent was found, and in addition a narrow vein of massive chalcocite was located in a fractured syenite. In Conjurer Bay, at the southeast corner of Great Bear Lake, two discoveries were made. One consists of chalcopyrite, chalcocite, bornite, and specularite in a long break in fractured syenite, and the other is a large area of brecciated rhyolite intruded by syenite containing galena and chalcopyrite.

In 1930 the Northern Aerial Minerals Exploration Co. prospected in both the Coppermine and Bathurst Inlet areas. In the Coppermine area, in addition to native copper, it discovered chalcocite and bornite in fissure veins and replacement deposits. The chalcocite is associated in fissure veins with quartz and carbonate and also is disseminated through the country rock, locally replacing it. The veins are from 3 to 6 feet wide and in the proportion of chalcocite range from low-grade ore to massive chalcocite with no gangue minerals. Bornite seems less common than chalcocite throughout the area, but one massive deposit is at least 12 feet wide. Chalcopyrite is not common but was found in cracks and disseminations in small amounts. The copper content in several of these discoveries is high, but it has not yet been demonstrated whether the available tonnage is sufficient to render their development profitable.

Bathurst Inlet

The copper-bearing area in Bathurst Inlet is distinct from the Coppermine River areas. The Southern Arctic Expedition examined some 150 islands ranging in size from a few hundred square yards to several square miles, as well as a part of the adjacent mainland. The Coppermine River series, the youngest in the area, here consists of basic lava flows with a few thin beds of tuffaceous conglomerate and ash, everywhere well exposed. The rocks dip in various directions at angles averaging about 6°, forming a shallow basin or basins. All the lavas are amygdaloidal basalts, in places with a little quartz. The thickness of the series is over 850 feet.

The native copper occurs as minute flakes disseminated throughout the dense groundmass of the basalts, as irregular grains and small masses filling or partly filling the branching gas cavities near the upper surfaces of the basalt flows, and as veins occupying fissures and shatter zones not confined to any particular horizon in the basalt flows. Few veins are as much as 3 inches wide. Numerous analyses were made and indicate that a tremendous tonnage of rock carrying 0.01 to 0.25 percent of copper is available, together with amygdaloidal material of undetermined amount carrying over 1 percent of copper, as well as the copper of the veins, some of which are filled with thin sheets of native copper and others carry over 4½ percent of flake copper. The deposits probably form an important reserve, but under present conditions they do not warrant the large expense necessary to prove and develop them.

British Columbia

At present there are only two producing copper camps in British Columbia—Britannia and Anyox. Copper Mountain, near Allenby, has large proved reserves of ore and is only waiting a return of better prices to reopen. Large tonnages of ore have been developed at the Coast Copper camp, on Vancouver Island. Many other occurrences worthy of further test are known in the Province, but the present price of copper deters their exploitation. Plate 3 shows the relation of the mineralized areas to the Coast Range batholith.

For many years the great copper-producing region of British Columbia was a section near the international boundary, including the mines at Phoenix and Deadwood, near Greenwood, and the Rossland mines, farther east. Phoenix, the principal camp, produced from 1900 to 1918; the ores of Rossland carried gold, copper, and silver, and production continued from 1894 to 1928.

At Phoenix and Deadwood the ore bodies lay in highly altered, supposedly Paleozoic limestone. At Deadwood the small area of sediments is surrounded and presumably also underlain by granodiorite, which intrudes the sediments as dikes and stocks. Near Phoenix the granodiorite does not crop out but may be represented by a few small intrusions of syenite and syenite porphyry. The plutonic rocks are presumably of Mesozoic age, possibly late Jurassic, and supplied the solutions that produced the ore bodies. The ore bodies were irregular lens-shaped replacement deposits in the limestone, usually at the contact of the limestone with underlying silicified tuffs or argillaceous sediments. They varied in size, some being small and the largest being 2,500 feet long, 900 feet wide, and 225 feet in maximum thickness. At Deadwood the ore consisted of chalcopyrite, pyrite, and magnetite, finely and uniformly disseminated through a gangue of actinolite, garnet, epidote, and quartz. At Phoenix specular hematite was more abundant than magnetite.

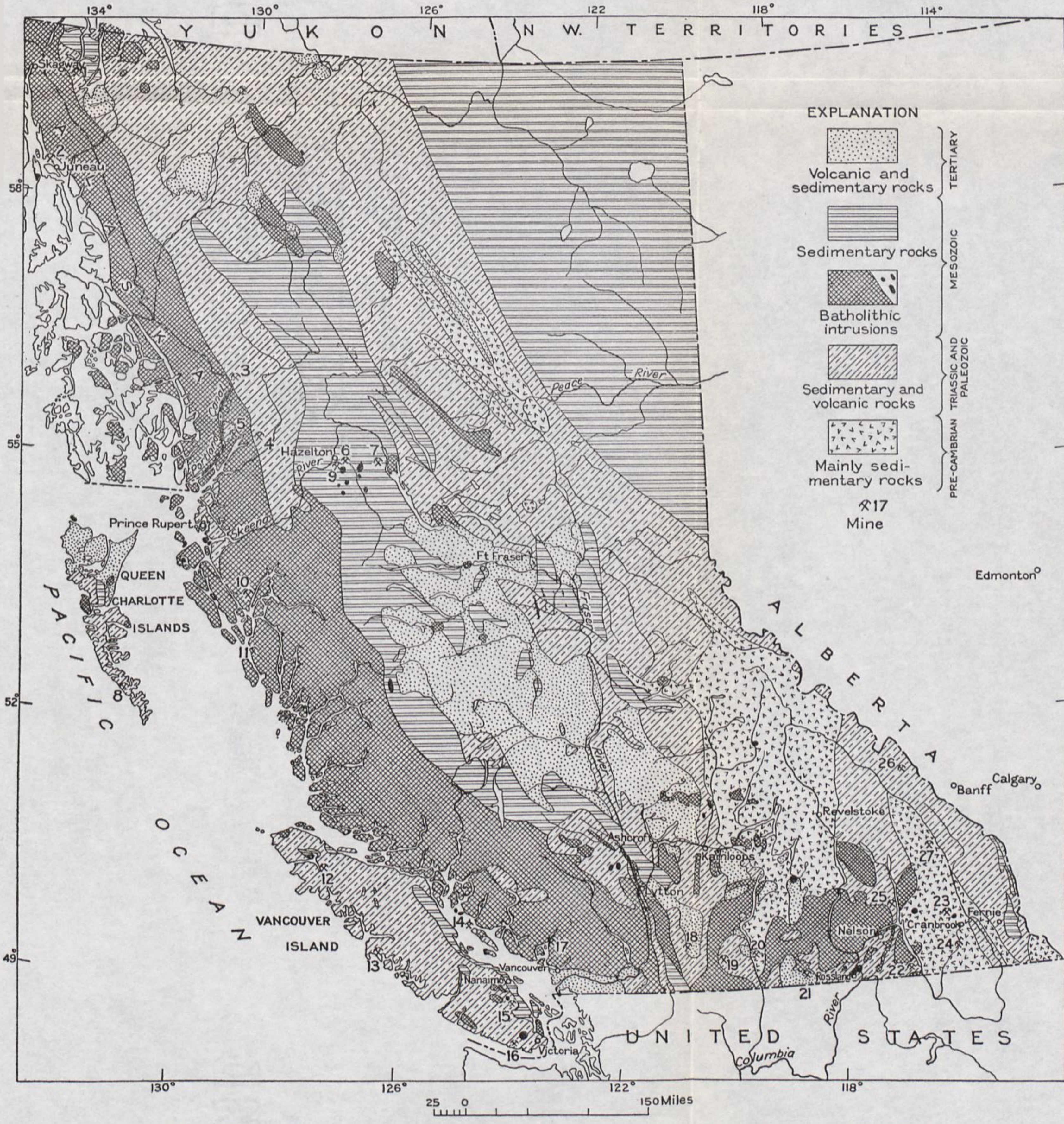
The chief mines of Rossland lay near the border of a body of Mesozoic monzonite that has intruded tilted Carboniferous slates containing a thick sill-like body of augite porphyrite. The slates and augite porphyrite are cut by granodiorite and by related diorite porphyrite. The ore deposits followed the trends of the irregular-shaped diorite porphyrite bodies and probably were genetically connected with these intrusives. The deposits were mainly veins and replacement deposits in the country rock along zones of fissuring or shearing, which followed different directions. These ore zones attained 4,000 feet in length and 150 feet in width and extended to great depths. The individual ore bodies along these zones were from 50 to more than 500 feet long, exceptionally 130 feet wide, and as a rule deeper than their length. The ore bodies were mostly lenticular masses grading into country rock, or tabular bodies terminating against fault planes or dikes. The ore consisted mainly of pyrrhotite and chalcopyrite in a gangue of country rock with some quartz and locally a little calcite. It averaged from 0.7 to 3.6 percent of copper, with 0.4 to 1.2 ounces of gold to the ton and a little silver.

Britannia mines

Location and history.—The Britannia mines, owned by the Britannia Mining & Smelting Co., Ltd., a subsidiary of the Howe Sound Co., of New York, lie in the Coast Range about 20 miles north of Vancouver. They are reached by steamers that make regular call at Britannia Beach, between Vancouver and Squamish. At Britannia Beach are the company's mill and general offices. A larger town known as Tunnel Camp is on Britannia Creek 2,100 feet above sea level, near the main portal of the mine. It includes the mine building, bunk houses, dwelling houses, and community buildings.

The deposits were reputedly discovered in 1888 by a Dr. Forbes while deer hunting, but he was unable to interest anyone in them. Ten years later the mineralized zone was rediscovered by James Oliver, a trapper, who staked 7 claims that became the nucleus around which the present property was built. Several changes in the ownership followed, and during that time an enormous body of low-grade ore was indicated by development work, and finally in 1908 the present company was organized.

Geology.—The deposits lie in a band of metamorphosed sediments and igneous rocks forming a roof pendant within the granodiorite of the Coast Range batholith. The band is 7 miles long and about 2 miles wide, and its component rocks trend about east and dip 70° S. The following table (22) summarizes the succession:



MAP SHOWING RELATION OF MINERALIZED AREAS IN BRITISH COLUMBIA TO THE COAST RANGE BATHOLITH

After Canada Geol. Survey Mem. 132.

Geologic formations in vicinity of Britannia mines

Period	Group	Formation		Lithology	Approximate thickness (feet)
Quaternary.				Stream deltas and rock debris. Bedded sand and gravel, overlain in places by unassorted glacial material.	
Tertiary (?).		Late dikes.		Basalts.	
Possibly Upper Jurassic.		Early dikes.		Both acidic and basic.	
Upper Jurassic (?).		Coast Range batholith.		Quartz diorite to granodiorite.	
Probably Upper Jurassic.		Britannia sills.		Albite dacite, dacite, and quartz dacite.	
Probably Triassic or Jurassic.	Britannia group.	Goat Mountain formation.	Upper.	Andesitic agglomerates, tuffs, and flows.	1,500
			Middle.	Chiefly basic sills with tuffs, flows, and shale.	8,000
			Lower.	Greenstones, metamorphosed andesite, etc. Rhyolitic volcanics and graywacke.	4,000
		Britannia formation.		Top not exposed.	
				Shale. Fragmental and massive metabasites.	5,300
				Unknown interval.	
				Arkose.	700
				Base unexposed.	

All the commercial ore deposits of the area lie within or close to the Britannia shear zone. This zone is confined entirely to the steeply dipping rocks of the Britannia formation and the included sills and consists of a tapering strip of sheared rock about 5 miles long trending northwest and dipping 40°–70° SE. The width of the zone varies; the maximum is a little less than 2,000 feet. This zone transects the strike of the Britannia formation at a low angle. Within it are fine green chloritic schists derived from the basic tuffs and flows, fissile soft "slates," and sheared phases of the Britannia sills. Most of the deposits lie in the last type, a quartz-sericite schist which is a sheared phase of the so-called "mine porphyry." The shear zone is apparently younger than the main batholithic intrusion, for sheared dikes in the zone are very similar to dikes that cut the batholith. The zone has been irregularly mineralized and holds large lenticular ore bodies consisting of highly silicified schists impregnated with and replaced by pyrite, chalcopyrite, and minor amounts of sphalerite. Anhydrite and gypsum occur in the schists, locally in lenses from 10 to 30 feet in width. On the lower levels of the mine the gypsum occurs as very narrow replacement veinlets in the anhydrite and coating nearby joint planes. Within 200 or 300 feet of the surface the anhydrite is completely replaced by gypsum, and still nearer the surface both minerals have been leached out.

The following minerals have been observed in the different ore deposits:

Hypogene minerals (*nonmetallic*)	*Hypogene minerals* (*metallic*)	*Supergene minerals*
Sulphur	Gold	Gypsum
Quartz	Magnetite	Copper
Octahedrite	Hematite	Chalcocite
Calcite	Pyrite	Covellite
Undetermined carbonate	Pyrrhotite	Marcasite
Barite	Chalcopyrite	
Anhydrite	Bornite	
Sericite	Sphalerite	
Aphrosiderite	Wurtzite (?)	
Chlorite	Galena	
Titanite and leucoxene	Tetrahedrite	
Albite		
Apatite		
Undetermined phosphate		

Ore deposits.—There are five ore bodies—from west to east the Jane, Bluff, Fairview, Empress, and Victoria. (See fig. 8.) Each of these is called a mine, as

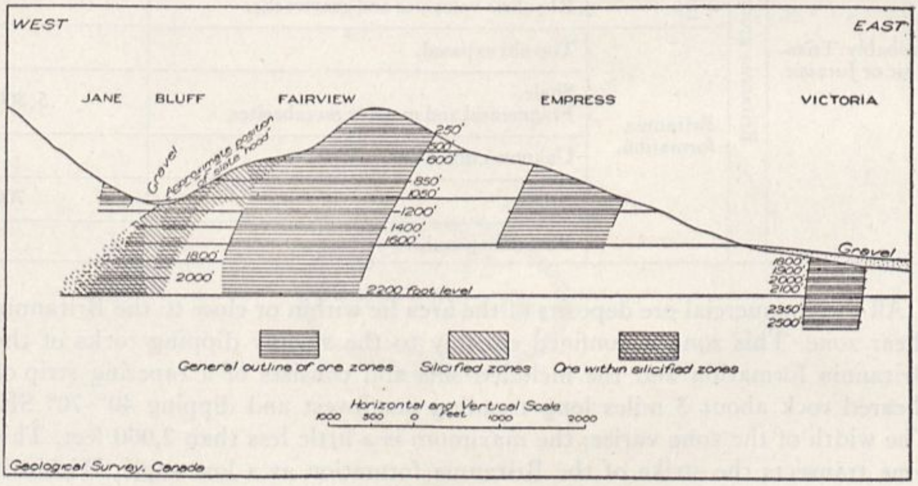


FIGURE 8.—Generalized longitudinal section of Britannia mines, British Columbia. (After Canada Geol. Survey Mem. 158.)

it is separated by 500 to 1,000 feet of barren ground from the next deposits. The last four are within the shear zone proper and are distributed at fairly regular intervals along its footwall (north) side. The Jane mine is a little south of the general strike of the footwall and is separated from the shear zone by several hundred feet of soft and highly metamorphosed argillites.

The distribution, the form, and to a certain extent the mineralogy of the ore deposits are controlled by major and minor structures of the shear zone. For example, all the important veins are in a green-mottled chlorite-sericite schist, but a silvery fissile sericite schist is invariably barren. Both schists are sheared phases of one of the Britannia sills, called the "mine porphyry." The Bluff ore body on the 1,050-foot and 1,200-foot levels is overlain by a capping of slate that plunges to the west; the Empress and Victoria deposits are also related to similar structures. The Fairview veins are related to minor structures in the shear zone. Dikes and premineral faults have also notably influenced the distribution of the ore.

The Jane deposit, the discovery claim, long since exhausted, shows two types of mineralization. Zinc ores, chiefly barite and sphalerite with small amounts of galena, tetrahedrite, and pyrite, have replaced bedded sediments; these ores in turn have been replaced by quartz and grade into siliceous copper ores consisting of quartz, pyrite, chalcopyrite, and variable amounts of sphalerite. To explain the apparently earlier formation of the barite and sphalerite it is postulated that the first ore solutions were cooled by the country rock, with the precipitation of low-temperature minerals, but as the flow of the solutions continued the rocks were heated, and higher-temperature minerals were deposited, replacing the earlier minerals.

The Bluff deposits are the most westerly in the shear zone proper. They consist of huge siliceous replacement deposits along the footwall of the sheared mine porphyry. Two distinct ore shoots, the westerly and the easterly, are recognized. The westerly shoot is blunt and terminates upward below the 1,200-foot level. It extends downward below the 2,200-foot level. The easterly ore shoot extends from the 1,800-foot to the 1,050-foot level, where it crops out as a conspicuous iron-stained bluff standing vertical for 100 feet. It contains two ore bodies, which coalesce above the 1,200-foot level, forming an irregular pipelike body capped by slates. The two parts of the easterly ore shoot are known as the "hanging wall" and "footwall" ore bodies. They plunge to the west in the same direction as the slate capping but at a much steeper angle. The ore bodies consist of silicified rock with more or less chlorite, sericite, and the sulphides. Of the sulphides, pyrite is the most abundant; chalcopyrite is the only one of economic importance. Sphalerite is present throughout; galena is not conspicuous but is common above the 1,400-foot level.

East of the Bluff, at fairly regular intervals along the footwall of the shear zone, are the Fairview, Empress, and Victoria deposits. The Fairview (fig. 9) shows two types of mineralization—(1) anhydrite bodies that have replaced both the hanging wall and the footwall from the 850-foot to the 2,200-foot level at least, and (2) lens-shaped masses carrying chalcopyrite. There are twelve chalcopyrite bodies, which occupy about 1,700 feet of the shear zone immediately west of the Bluff mine. Eight of them, numbered 0 to 7, are fairly regular tabular deposits occupying the footwall section of the shear zone. The remaining four, numbered 8 to 11, are broad irregularly mineralized zones in the hanging-wall section of the shear zone. The footwall veins are essentially replacement deposits along fracture zones developed when the mine porphyry was sheared. They consist of reticulating masses of quartz and sulphides enclosing variable amounts of schist. The hanging-wall veins consist of four broad zones of commercial ore separated by bands of mineralized schist. After the richer streaks, or veins, were mined by underground methods, the remaining portion was mined from the surface. The hanging-wall veins differ from the footwall veins in that the ore minerals are carried by a great number of narrow individual veinlets rather than by a relatively narrow zone of interlocking veinlets and massive

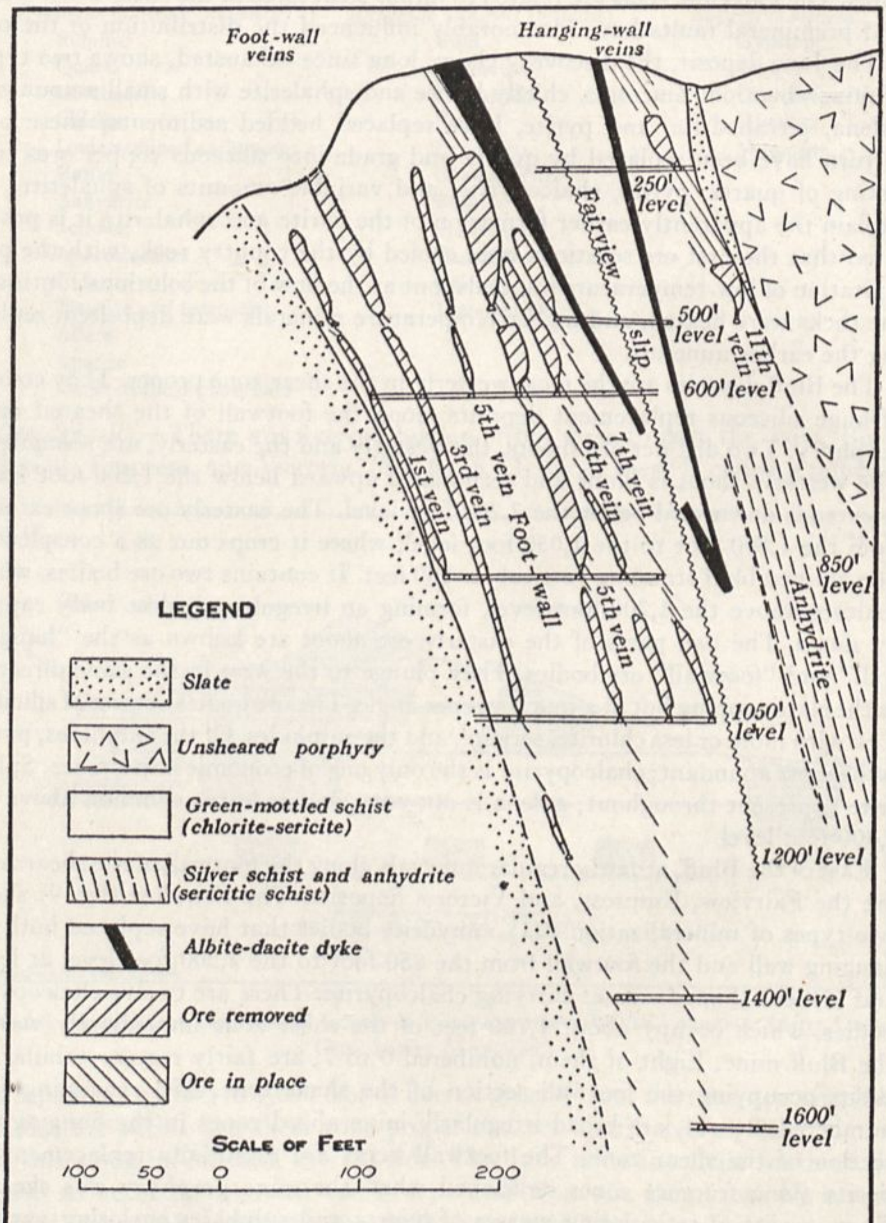


FIGURE 9.—Transverse section of Fairview mine, British Columbia. (After Canada Geol. Survey Mem. 158.)

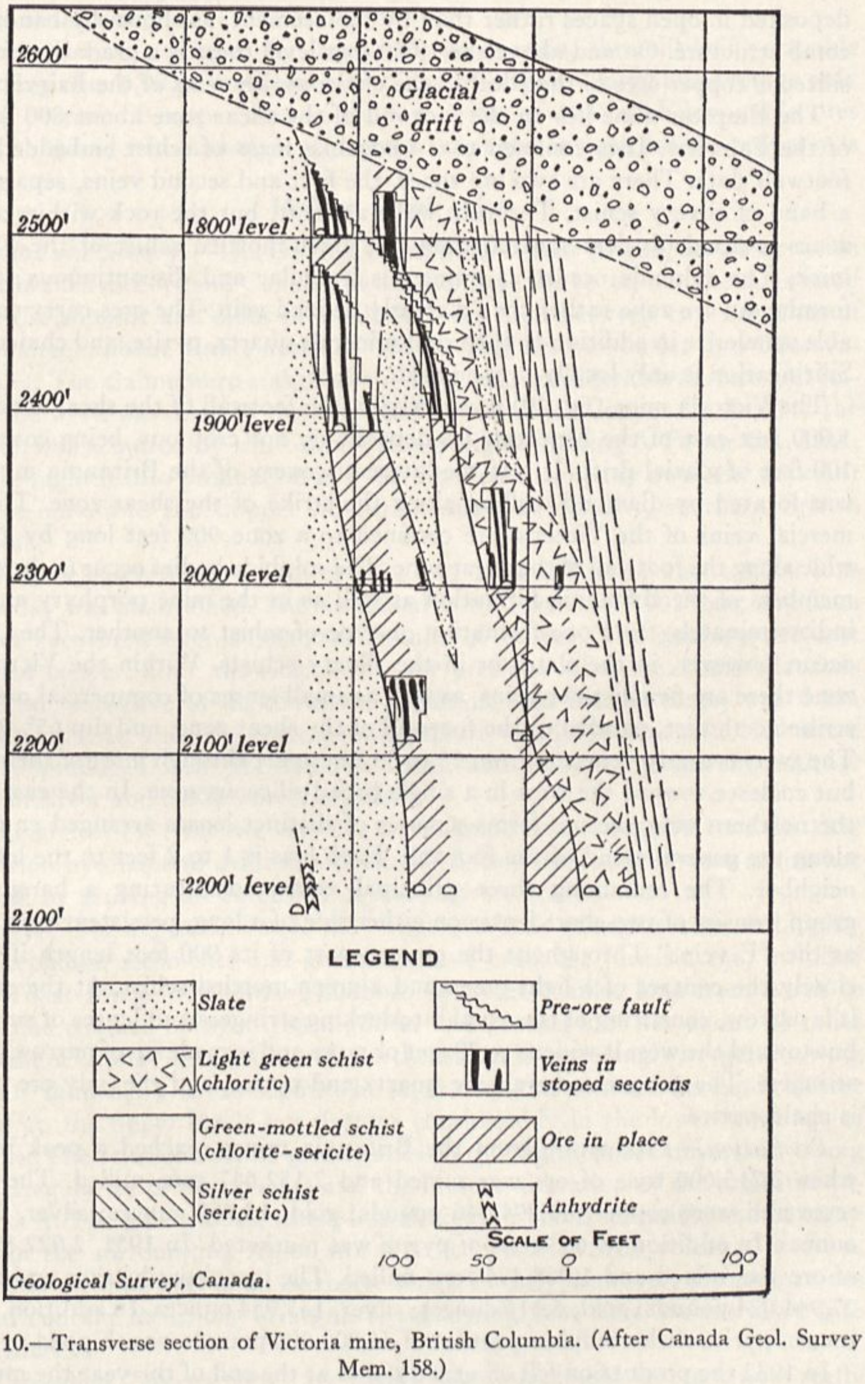


FIGURE 10.—Transverse section of Victoria mine, British Columbia. (After Canada Geol. Survey Mem. 158.)

replacement deposits. Much of the sulphide of the hanging-wall veins has been deposited in open spaces rather than by replacement, as shown by banding and comb structure. On and above the 1,050-foot level there is a gradation from the siliceous copper ores of the Bluff to the chalcopyrite veins of the Fairview.

The Empress mine lies on the footwall of the shear zone about 800 feet east of the Fairview. It is confined to a wedgelike mass of schist embedded in the footwall slate. There are two ore zones, the first and second veins, separated by a band of silvery schist. The vein walls are soft, but the rock within the vein zones is decidedly less sheared than the green-mottled schist of the Fairview mine. The sulphide occurs as numerous irregular and discontinuous stringers forming an ore zone rather than a clearly defined vein. The ores carry considerable sphalerite in addition to the usual minerals quartz, pyrite, and chalcopyrite Silicification is only locally pronounced.

The Victoria mine (fig. 10) is directly on the footwall of the shear zone about 1,000 feet east of the Empress. Its deposits do not crop out, being covered by 100 feet of glacial drift. It was the latest discovery of the Britannia mines and was located by diamond drilling along the strike of the shear zone. The commercial veins of the Victoria are confined to a zone 900 feet long by 200 feet wide along the footwall of the shear zone. The sulphide bodies occur in the sheared members of the Britannia formation as well as in the mine porphyry and cross indiscriminately from one formation or type of schist to another. They do not occur, however, in the slates or in the silvery schists. Within the Victoria ore zone there are five distinct veins, as well as small lenses of commercial ore. They strike northwest, parallel to the footwall of the shear zone, and dip 65°–90° SW. The two northerly veins are from 25 to 30 feet apart through most of their length but coalesce toward the west in a single broad siliceous zone. In the east half of the northern vein the ore forms a series of distinct lenses arranged en échelon along the general trend of the footwall. Each lens is 1 to 2 feet to the left of its neighbor. The remaining three principal veins, constituting a hanging-wall group, consist of two short lenses on either side of a long, persistent vein known as the "E vein." Throughout the greater part of its 900-foot length it follows closely the contact of a light-green and a green-mottled schist. At the east end it is narrow, consisting of the usual interlocking stringers and lenses of sulphides, but toward the west it widens to 20 feet or more and is made up of narrow parallel stringers. The gangue minerals are quartz and pyrite, and the only ore mineral is chalcopyrite.

Production.—Production from the Britannia mines reached a peak in 1930, when 2,215,600 tons of ore was mined and 2,152,647 tons milled. The metals recovered were copper, 44,294,446 pounds; gold, 13,062 ounces; silver, 203,345 ounces. In addition 36,653 tons of pyrite was marketed. In 1931, 2,022,321 tons of ore was mined and 1,968,494 tons milled. The metal production was copper, 27,944,024 pounds; gold, 5,315 ounces; silver, 135,954 ounces. In addition, 34,000 tons of pyrite with a sulphur content of 34,000,000 pounds was shipped to Japan.

In 1932 the production fell off greatly, and at the end of the year the mine was working about three-quarters time, and the mill about 10 days a month. The ore mined and milled during the year amounted to 773,508 tons, mostly from the East Bluff deposit, where the gold content is slightly higher than in the other sections of the mine.

The property is equipped for large-scale production, the mill being capable of handling over 6,000 tons of ore a day. The reserves are large but average only about 1 percent of copper, and at the low prices of 1933 such low-grade ores cannot be mined with a margin of profit, so that the outlook for the property is obscure.

Hidden Creek mine

Location and history.—The Hidden Creek mine is near Anyox, on Observation Inlet, a branch of Portland Canal. The smelter is at the coast, but the mine itself lies on the summit and sides of a hill 920 feet high between two branches of Hidden Creek, about a mile north of Granby Bay near its outlet into Observation Inlet. The claims were staked about 1902, and considerable surface and underground work was done on them by the Hidden Creek Copper Co. In 1911 the property was acquired by the Granby Consolidated Mining & Power Co., Ltd., which brought it into production in 1914. The same company owns the adjacent Bonanza mine and the Copper Mountain mine, at Allenby, southern British Columbia.

Production and reserves.—During 1931 and 1932 milling of about 5,000 tons of ore a day was maintained. The ore mined in 1931 was 1,479,905 tons, and from this was recovered over 34,000,000 pounds of copper. The average net cost of refined copper, after allowing credits for precious metals and miscellaneous income but exclusive of depreciation, depletion, and income taxes, was 6.821 cents a pound. In 1930 the corresponding figure was 9.796 cents. In 1931 there was also produced from the Hidden Creek and Bonanza properties 322,649 ounces of silver and 5,602 ounces of gold.

At the end of 1931 the ore reserves at the mine were 4,644,590 tons. In 1932 exploration by diamond drilling was curtailed, but the reserves were somewhat increased by proving the extension of some old ore bodies.

Geology.—The deposits lie near the center of a body of argillaceous and highly metamorphosed sediments and greenstones of probable Jurassic age, included in the Coast Range batholith. This body is about 9 miles long from north to south. The contact between the argillites and greenstones lies about 1½ miles northwest of Granby Bay and trends northeast but is exceedingly irregular, owing in part to faulting. The ore deposits lie on or near this contact. Its dip is almost vertical on the upper levels but flattens considerably in the lower workings of the mine. The relations of the greenstones to the argillites are uncertain, owing to the irregularity of the contact and the intense alteration of the argillites adjacent to it. The greenstones, where less altered, resemble andesites and in many places in the surrounding region are interbedded with true volcanic breccias, apparently forming part of an extrusive series. Locally, however, the greenstones cut and contain inclusions of argillite, suggesting that they are intrusive into the sediments.

The so-called "greenstones" are highly metamorphosed and are now really hornblende schists, consisting of 70 to 90 percent of a pale-green hornblende, with chlorite, andesine, orthoclase, quartz, biotite, talc, epidote, and in many places small amounts of pyrite. Much more quartz is present near the ore bodies, with actinolite, tremolite, calcite, sphene, and leucoxene. The argillites also are highly metamorphosed and consist chiefly of biotite, quartz, pyrite, and pyrrhotite, with considerable carbonaceous material. In the vicinity of the ore bodies large quantities of talc, sericite, and quartz are present. In places silicification has been almost complete. Interbedded with the altered argillites are thin beds of sandstone and a few thin limestones. The rock of the surrounding Coast Range

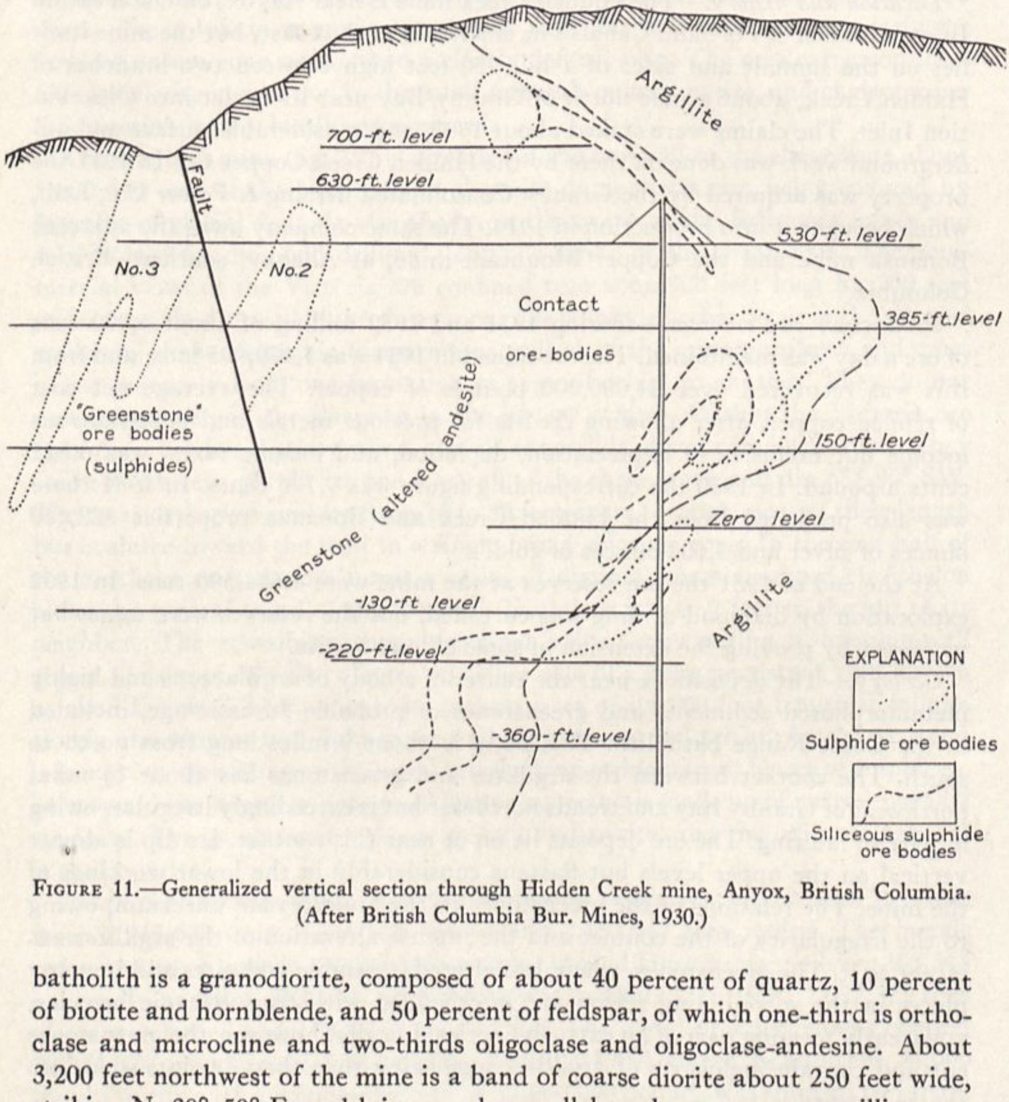


FIGURE 11.—Generalized vertical section through Hidden Creek mine, Anyox, British Columbia. (After British Columbia Bur. Mines, 1930.)

batholith is a granodiorite, composed of about 40 percent of quartz, 10 percent of biotite and hornblende, and 50 percent of feldspar, of which one-third is orthoclase and microcline and two-thirds oligoclase and oligoclase-andesine. About 3,200 feet northwest of the mine is a band of coarse diorite about 250 feet wide, striking N. 20°–50° E. and lying nearly parallel to the greenstone-argillite contact. The only other rocks nearby are numerous dikes of all sizes, the largest several hundred feet in width. They range in composition from acidic quartz porphyry, granite, and syenite through diorite and andesite to kersantite. They vary considerably in age, but all are probably younger than the ore deposits. Over 100 of these dikes have been mapped in the mine. Though some are left as supporting pillars, most of them have to be mined, thus considerably lowering the grade of the ore.

Ore bodies.—There are six ore bodies. A seventh, the Bonanza, is usually regarded as a separate mine. Nos. 1 to 5 are clustered close together around the apex of a spur of greenstone about 2,500 feet square, which juts into the argillites in a northeast direction. No. 6 lies 1,300 feet to the southwest, on the southeast side of this greenstone spur. Nos. 1, 4, 5, and 6 lie on the contact of the argillites and greenstones, where the argillites are much crumpled and the greenstones especially schistose. Nos. 1 and 5 are developed at the most abrupt turn in the strike of the greenstone-argillite contact, and these ore bodies are richer where the slate overhangs the ore. Nos. 2 and 3 lie in the highly schistose greenstone and at the time of their deposition were probably roofed by slate. They are really two parts of a single ore body separated by an eastward-dipping fault (fig. 11).

The ore bodies are large. Nos. 1 and 5 have a combined length on the 530-foot level of about 1,240 feet and an average width of 150 feet. Nos. 2 and 3 have a combined length of 750 feet and a width of 240 feet. No. 4 lies chiefly above the 530-foot level. It is triangular in plan, with a length on the 760-foot level of 560 feet. The present workings extend over a vertical range of more than 1,000 feet.

The gangue is silicified argillite and greenstone. The common metallic minerals are pyrite, pyrrhotite, chalcopyrite, sphalerite, magnetite, and arsenopyrite. Ore body 4 is different from the others; it is of low grade and consists of a central largely pyritic core surrounded by a shell of nearly pure pyrrhotite. In general the pyrite, arsenopyrite, and magnetite are older than the pyrrhotite, zinc blende, and chalcopyrite, which were deposited simultaneously. The ores are regarded as the result of replacement of greenstone and argillite by solutions from the Coast Range batholith. They average about 2 percent of copper and carry a little gold and silver.

Bonanza mine

The Bonanza mine, owned by the Granby Consolidated Mining, Smelting & Power Co., Ltd., lies 3½ miles south of the Hidden Creek mine, on Bonanza Creek, 3,200 feet from the shore of Granby Bay. The mine was brought into production in February, 1929.

The deposit resembles those of Hidden Creek and lies in schistose greenstone near its contact with argillite (24, 1930, p. 81). Numerous dikes ranging in composition from aplite to lamprophyre cut the rocks in an east-west direction. The ore zone appears to occupy a flat anticlinal fold. The south wing dips 10°–15° W. but about 500 feet south of the outcrop steepens to 30° W., at the same time narrowing and increasing in grade. This zone has been developed both north and south of Bonanza Creek. On the south side it is from 80 to 90 feet thick. The best ore appears to occupy the central part of the zone in widths as great as 70 feet, with the best grade in 10- to 40-foot widths along the footwall. In this zone bands several feet wide of solid pyrite and chalcopyrite are separated by belts of sheared chlorite schist, also ore-bearing. The best ore shoots are very irregular in shape.

In 1931 the mine produced 96,984 tons of ore. The reserves at the end of that year were estimated to be 322,180 tons, averaging about 2.49 percent of copper.

Maple Bay deposits

At Maple Bay, on the east side of Portland Canal about 30 miles from its head and 7 miles due west of Anyox, are several copper claims lying in the same series of rocks as the Hidden Creek deposits. Some of these claims have been optioned at different times by the Granby Consolidated Mining, Smelting & Power Co. The deposits are quartz veins and silicified zones paralleling the trend of the enclosing hornblende schists. The ore is chiefly chalcopyrite and pyrrhotite in a gangue of quartz and silicified country rock. In places ore bodies 200 to 400 feet long and 8 to 20 feet wide have been developed. The ore on the whole is of low grade, the average copper content of most of the ore shipments being around 3 percent, though local masses run higher. There are also a little gold and silver, as in the Hidden Creek deposits.

Copper Mountain mine

Location and history.—Copper Mountain (20) is a nearly flat-topped elevation between the Similkameen River on the west and its largest tributary, Wolf Creek, on the east. The Copper Mountain mine lies 13 miles south of Princeton, which is 150 miles east of Vancouver, on the Kettle Valley Railway. A good road up Wolf Creek connects it with Princeton, and the haulage level of the mine, which emerges on the side of Similkameen Valley 1,000 feet lower than the camp, is connected with the Kettle Valley Railway by a spur following the Similkameen Canyon. This spur passes through the town of Allenby, 6 miles south of Princeton, where the concentrator is located.

High-grade copper ore was known at Copper Mountain as early as 1884, but it was not until 1892 that the first claim, the Sunset, was staked by R. A. Brown. This claim has since proved to be the richest and is the center of the most recent large-scale operations. Many claims were soon taken up nearby, and in 1900 Mr. Brown organized the Sunset Copper Co. and spent about $16,000 in sinking a shaft and doing other underground work. In 1905 the British Columbia Copper Co., which had been operating in the Greenwood district, took a lease and bond on the Sunset and some adjoining claims and formed the South Yale Copper Co., but the following year this bond was dropped. In 1912 the property was again taken over by the British Columbia Copper Co., which was reorganized as the Canada Copper Corporation. The new company began a vigorous development campaign, but at the outbreak of war in 1914 all work stopped. In 1916 the high price of copper induced resumption of operations. The mine was developed to produce 2,000 tons a day, an elaborate camp was built at the mine, and a concentrator and another camp were erected at Allenby. Delay in the building of a power line and the spur railway prevented operation until late in 1918. The first mill runs were unsuccessful, and as the price of copper had dropped below that thought necessary for profitable production, the mine and mill were closed down. Up to this time over $4,000,000 had been expended, and no copper had been produced.

In 1923 the property was taken over by the Granby Consolidated Mining, Smelting & Power Co., Ltd., and considerable capital was spent in conditioning the mine and mill, but before the end of the year the attempt was abandoned. In the winter of 1925–26 the company, under new management, again undertook operations. The concentrator was remodeled for the third time and before the end of 1926 was operating successfully. A production of 2,000 to 2,500 tons of ore a day giving a concentrate carrying about 30 percent of copper besides a little gold and silver was maintained until December, 1930, when the property was once more closed down.

Geology.—The oldest rocks in the general region belong to the Cache Creek series, which consists of limestones and other sediments with considerable volcanic materials, over 10,000 feet in total thickness and believed to be mainly of late Carboniferous age. At one time it occupied most of the region but has since been replaced by intrusives or covered by later formations, so that it is now found only in small isolated patches. The Cache Creek strata are overlain by volcanic rocks and sediments named by Dawson the "Nicola series," in part at least of Triassic age. Locally the two series appear to be conformable, but whether this is so everywhere is not known.

Batholithic intrusions of dioritic composition began possibly in late Jurassic time and continued through Cretaceous into Tertiary time. During the same period the older formations were folded. In Tertiary, possibly Eocene, Oligocene, or Miocene time great thicknesses of volcanic rocks were extruded, and with them are locally associated some sediments. The youngest batholithic masses appear about contemporary with some of these Tertiary volcanic rocks. During the Pleistocene the region was heavily glaciated, but as it lay in a basinlike depression the movement of the ice sheet as a whole was slight, so that except very locally there was little erosion.

In the immediate vicinity of Copper Mountain the oldest rocks are a thick series of volcanic tuffs, flows, and breccias of andesitic, basaltic, and trachytic composition, known as the "Wolf Creek formation." They are probably to be correlated with the Nicola series, of Triassic age. The complete succession of rocks (21) is as shown in the table on page 126.

The Lost Horse intrusives are equigranular plutonic rocks forming small irregular intrusions north of the Copper Mountain property. They consist of two types—a very light colored siliceous augite diorite and a pinkish-gray biotite monzonite or syenite. As these intrusives were mineralized by solutions that apparently originated in the parent magmas of the Copper Mountain and other stocks, they were probably formed early, but they are so similar to these stocks in composition that they may be of roughly the same age.

The Copper Mountain complex stock is the largest of the three near the mine and occupies an elliptical area of several square miles, its major axis, about 5 miles long, trending northwest. The stock is genetically related to the large copper deposits; the Copper Mountain ore deposits lie against its northeast side, and several leaner copper deposits occur in its western and southern parts. In composition the rock varies, in some places gradually and elsewhere abruptly, from a syenogabbro at the outer margin to nearly pure feldspar (orthoclase and albite) in a central core nearly 1 mile in diameter. The Voigt stock lies northeast of the Copper Mountain stock, and the Smelter Lake stock is probably connected with the Voigt at shallow depth. These two intrusive masses, unlike the Copper Mountain stock, are nearly uniform in composition and consist of dark medium-grained augite diorite or syenodiorite composed essentially of plagioclase, augite, and hornblende, with varying small amounts of orthoclase and biotite. Pegmatite dikes and veins are abundant in the region, particularly in and near the three stocks, and, as already indicated, the Copper Mountain stock has a cylindrical core of pegmatite 1 mile in diameter.

Geologic formations at Copper Mountain

Age		Formation	Lithologic character
Quaternary.	Recent.		Alluvium.
	—Unconformity—		
	Pleistocene.		Glacial drift.
Unconformity.			
Tertiary.	Post-Eocene.	"Tertiary volcanics."	Flows, breccias, and necks of enstatite andesite and basalt.
		"Mine" dikes.	Felsite porphyry, quartz porphyry, and granophyre.
Tertiary (?).		Verde Creek granite.	Granite.
Mesozoic.		Pegmatite dikes.	Monzonite and syenite pegmatite.
		Voigt stock.	Augite diorite and syenodiorite (orthoclase diorite).
		Smelter Lake stock.	Augite diorite and syenodiorite (orthoclase diorite).
		Copper Mountain stock.	Orthoclase-albite pegmatite, syenodiorite (orthoclase diorite), monzonite, and syenogabbro (orthoclase gabbro).
Unconformity.			
Mesozoic (?).		Lost Horse intrusives.	Stocks and sills of augite diorite and diorite porphyrite.
	Triassic (?).	Wolf Creek formation.	Andesite, basalt, trachyte, breccias, flows, and tuffs.

All these intrusive rocks are considered differentiates of a basic magma (syenogabbro) intruded after the Wolf Creek volcanic rocks had been deformed. The main body of this magma is not exposed, but its presence at depth is inferred from the exposures of its satellitic stocks and dikes. The Copper Mountain stock is believed to form a cupola of the main magma chamber in which volatile components accumulated. The lithologic changes in the stock from border to core suggest differentiation in place from a single magma.

Northeast of the property is a small intrusive known as the "Verde Creek granite," which differs from all the other rocks of the district in containing about 50 percent of quartz. It cuts the Voigt stock and Wolf Creek volcanic rocks and greatly resembles the nearby Otter granite, of definitely post-Oligocene age.

A large number of white or creamy-white granophyre and felsite porphyry dikes known as the "Mine dikes" are conspicuous at Copper Mountain. They range from less than a foot to 150 feet in width, and some have been traced for over a mile. They commonly split and coalesce again, thus enclosing large lenses of the intruded rock. They cut the Wolf Creek formation, the stocks, the pegmatite veins, and the ore but are themselves unmineralized. These dikes are unlike the Verde Creek granite and may be of late Tertiary age. They are particularly abundant in the mine, and as the ore cannot be extracted without their removal, they have added considerably to mining costs.

Still younger dikes, possibly related to the Tertiary volcanic rocks, occur at Copper Mountain. They are fresh, fine-grained, in places highly amygdaloidal augite andesites, range in width from 1 to 6 feet, and mostly trend normal to the Mine dikes.

The Tertiary volcanic rocks do not occur at the mine but crop out in a small area to the north. Similar rocks nearby rest conformably on supposedly Oligocene sediments.

Ore deposits.—The Copper Mountain mine exploits bornite-chalcopyrite deposits associated in position and origin with the Copper Mountain stock. A little magnetite and pyrite and large quantities of orthoclase, albite, augite, biotite, epidote, and zoisite of the same general age and origin are associated with the copper sulphides. In the surrounding region there are two other types of copper deposits—chalcopyrite-hematite deposits related to and situated in the Voigt stock and numerous chalcopyrite-pyrite deposits occupying a wide belt to the north of Copper Mountain. The Copper Mountain mine itself has one ore body of this second type. The chalcopyrite-hematite deposits as a group are not as promising as the other two types.

Most of the bornite-chalcopyrite ores of Copper Mountain occur in several contiguous ore bodies in the fragmental volcanic rocks of the Wolf Creek formation adjacent to the northeast sector of the somewhat circular contact of the stock. Similar ores are present in the gabbro phase of the stock and in pegmatite dikes, and considerable copper, though not sufficiently concentrated to form ore, is present in the pegmatite core of the stock.

The main ore bodies lie along a contact zone where for a distance of 2½ miles the fragmental rocks have been dynamically and hydrothermally altered to a marked degree. Apparently the rocks were first intensely foliated parallel to the gently curving vertical contact of the stock. Accompanying this schistose structure is a well-defined set of steeply dipping straight, narrow, parallel fractures, striking nearly normal to the schistosity and containing the bulk of the ore minerals. As a rule these cross fractures range in width from a fraction of a millimeter to several centimeters, but they average a few millimeters. The wider ones have doubtless been somewhat enlarged by replacement. In length they vary greatly; some have been traced in underground workings for 20 feet. The tenor of the ore is directly related to the spacing of the ore fractures, which in 2 percent ore average about 2 inches apart. Where the fractures are much more closely spaced the grade of the ore rises to 3 and in places 4 percent.

The dynamic metamorphism was accompanied by pronounced metasomatism in the zone extending 200 to 300 feet outward from the gabbro contact. Biotitization predominated in the inner zone, outside of which, but somewhat overlapping it, were developed large quantities of green pyroxene. Still later, pegmatitic and ore minerals were introduced along the fractures.

The ores differ markedly in composition from the other copper ores in British Columbia, chiefly in the large proportion of bornite, the almost entire absence of pyrite and pyrrhotite, the large amount of syenite pegmatite, and the absence of quartz. Other peculiarities are the presence of pyroxene both as a primary igneous mineral and as an abundant metamorphic and gangue mineral, and the presence of orthoclase in the syenogabbro, in the pegmatite veins, and as gangue. The metallic minerals recognized in the ore are bornite, chalcopyrite, pyrite, magnetite, chalcocite, covellite, malachite, azurite, hematite, galena, and sphalerite. The gangue minerals are augite, orthoclase, albite, oligoclase, biotite, epidote, zoisite, sericite, calcite, quartz, scapolite, apatite, garnet, and chlorite.

A chalcopyrite-pyrite deposit occurs on the Princess May claim of the main group of the Copper Mountain mine, near a small mass of acidic diorite. It lies about 500 feet north of an ore body of the bornite type, into which it merges, the mineralization having been continuous between the two ore bodies. Its length and depth are not known, but drilling and trenching have shown a width of 200 feet. It averages 1.5 percent of copper and contains a little gold.

Numerous other chalcopyrite deposits occur north of the mine. They consist of usually indefinite, irregular disseminated deposits of the two sulphides in various members of the Wolf Creek formation and the Lost Horse intrusives, generally near the intrusive contacts, and appear to have been formed by high-temperature solutions following only poorly defined zones of structural weakness. They appear to be really contact-metamorphic deposits related to the Lost Horse intrusives. The minerals introduced, named in order of abundance, are sericite, pyrite, feldspars, epidote, zoisite, chalcopyrite, magnetite, actinolite, augite, calcite, leucoxene, scapolite, and garnet. None of these minerals are abundant, and usually the original host rocks can be readily recognized. The low tenor and irregularity of these deposits will tend to make their mining difficult and expensive.

The Copper Mountain mine has opened up two main and several smaller ore bodies. The two main ones are the Sunset and the Contact. The Contact ore body closely follows the border of the Copper Mountain stock throughout. The Sunset ore body, which is about 700 feet long on level 3, has decreased on level 5 to a length of 400 feet. It varies in thickness; the maximum is 150 feet. The Contact ore body is 400 feet long on the outcrop and 2,570 feet long on level 6. Its maximum width is 100 feet. The ore persists to a vertical depth of more than 1,200 feet, as shown by workings.

The ore in the mine, as developed at present, averages around 1.74 percent of copper with small amounts of gold and silver. The latest statement of the Granby Co. regarding the property gave ore reserves estimated at 9,895,069 tons.

Coast Copper mine (21)

Location and history.—The property of the Coast Copper Co., Ltd., lies in the northern part of Vancouver Island, southeast of Quatsino Sound. A road, broken by two stretches of water on Alice and Kathleen Lakes, extends from Jeune Landing, on Neroutsos Inlet, a branch of Quatsino Sound, to the property, a total distance of nearly 15 miles. Autotrucks and gasoline launches are used for the transportation of passengers and supplies. The property includes about 70 claims on a steep and heavily wooded mountain side sloping northeastward to Elk Lake.

The outcrops were discovered in 1911. Claims were taken up, and in 1915 underground work, including the driving of a 500-foot crosscut tunnel, was carried out by the Quatsino Copper Co. In 1926 the Consolidated Mining & Smelting Co. of Canada organized the present company. Except for a period of inactivity in 1921 and 1922, development was continuous until 1931, resulting in over 4 miles of underground workings and many thousand feet of diamond drilling. A stage has been reached where, with return of better prices, production is assured.

Geology.—The rocks of the region consist of the Vancouver group and granitic intrusives related to the Coast Range batholith. The Vancouver group, of Triassic and perhaps in part Jurassic age, consists of a thick assemblage of volcanic flows and fragmental rocks interbedded with limestone, argillite, quartzite, and other sediments. The Coast Range intrusives consist of granitic stocks, dikes, and irregular masses. In certain small areas the Vancouver group is overlain by conglomerate, sandstone, and shale of Cretaceous age, which are not known to be cut by the Coast Range intrusives.

On the Coast Copper property rocks of the Vancouver group are cut by an irregular intrusive which ranges in composition from anorthositic gabbro to quartz diorite and granodiorite. The northeast border of this mass trends northwest along the top of the hill near the southwestern limit of the property. Northeast of the gabbro, limestone with a few interbedded lava flows and cut by many basic dikes is exposed at intervals. It strikes northwest and dips 30°–50° SW., toward the granite. The limestone is gray to white and mostly finely crystalline except near the intrusive contacts, where it is very coarse grained. To the northeast the limestone is underlain conformably by a thick volcanic series, including andesite, basalt, and porphyritic flow types. The andesites, the most abundant variety, are fine- to medium-grained green chloritic rocks, in places amygdaloidal. Associated with the volcanic rocks are irregular masses of basic feldspar porphyry in which are prominent white or greenish feldspar phenocrysts in a green fine-grained or clearly crystalline base. They resemble certain porphyritic dikes that cut the volcanic rocks and limestone but seem to grade into and form a part of the volcanic rocks, which they resemble in composition, and it is probable that they were formed during the volcanic period. The dikes that cut the sediments and volcanic rocks are of two ages. The older ones are fine-grained dark-green varieties, which are mineralized in places and may represent feeders for overlying flows. The others are porphyritic types that locally cut the ore zone and are therefore younger than the mineralization.

Ore deposits.—The mineralized zone, which occurs at the contact of the limestone with the underlying volcanic rocks, has been exposed on the surface for about 3,000 feet by closely spaced open cuts and has been picked up at intervals for an additional mile or more. Its width ranges from a few feet to about 100 feet. The chief minerals are garnet, epidote, magnetite, and calcite, with diopside, actinolite, and chlorite in minor amounts. Quartz occurs sparingly, mostly as small mineralized veins in the footwall. The ore minerals are chalcopyrite and bornite, which, with sporadic small quantities of pyrrhotite and pyrite, form veins, lenses, tabular bodies, and disseminated deposits in the silicates and magnetite. Generally the mineralized zone is divided into a hanging-wall and a footwall section by a sheet of dark-green to nearly black basaltic rock, which is apparently a volcanic flow interbedded with the limestone. At the mine it is called the included "diorite." Its width is irregular, changing abruptly from 10 or 20 feet to 80 feet or more, and it is not present everywhere in the mineralized zone. The footwall section of the deposit is generally the more productive. The main footwall is everywhere andesite, generally either silicified or partly replaced by silicate or converted to a soft brown or green rock in which chlorite and tiny nests of brown biotite are abundantly developed. In the limestone between the mineralized zone and the gabbro are numerous small showings of silicate, magnetite, and chalcopyrite, occurring principally along basic dikes or at the contacts of flows interbedded with the limestone. None of these appear to be of economic importance.

The mine is developed on levels 5, 7, 8, 10, 12, 14, and 16, and adits connect levels 5 and 8 with the surface. These adits are 400 feet and 2,100 feet long respectively, both entirely in the footwall volcanic rocks. No. 8 is the main haulage level, and the lower levels are reached by a winze from it. This level has explored the mineralized zone for over 4,200 feet. The main shaft extends below level 16, more than 1,400 feet below the surface. The most recent work (1930) on the lower levels was disappointing. No large shoots of commercial ore were opened, although large lenses of magnetite with a little copper were indicated.

Most of the ore is in the part of the mine south of the shaft. It occurs as shoots in the silicate-magnetite zone, much of which is either barren or too sparingly mineralized to constitute ore. On the upper two levels chalcopyrite is the only important ore mineral, but on the lower levels bornite is also abundant, chiefly as veins and disseminated replacement deposits in the magnetite. The veins and lenses of chalcopyrite range from mere stringers to bands 3 feet or more wide, and a series of these may continue for 100 or even 300 feet along the zone. Pyrite and pyrrhotite are only sparingly developed.

In parts of the mine considerable hard gray felsite occurs in the mineralized zone, chiefly as tabular or lenticular bodies conformable to the trend of the zone. Where the adjoining rock is andesite the contacts are generally gradational, and in several places the felsite includes shadowy areas that resemble altered, partly replaced andesite. Gunning believes that much of the felsite was formed by the replacement of original andesite or limestone by feldspar and quartz. However, dikes of apparently indistinguishable material occur underground, suggesting that prior to the mineralization several feldspathic dikes (felsite) were injected into the Vancouver group and that at the same time emanations, probably from the same source, extensively replaced the country rock in the present mineralized zone, forming tabular bodies resembling the dikes. After this period of injection and replacement, silicates, magnetite, and the sulphides were introduced, and where the felsite was crushed or fractured, they veined and replaced it. Where the felsite remained unfractured, however, the country rock was more susceptible of replacement. As the replacement within the main zone was practically complete, the tabular felsite bodies stand with sharp contacts against the silicates and magnetite. The sulphides were later than the silicates and magnetite.

The deposit is offset both along the strike and down the dip by numerous faults. The largest horizontal offset observed is one of 250 feet in the bed of Canyon Creek, along a premineral fault. It appears underground that some of the largest displacements have occurred along very inconspicuous fault planes, while along other faults with thick gouge there has been little offset. The fault problem is very important in the mine, particularly in the northern part of the workings. For long stretches, however, there has been little or no notable faulting, and here the best ore bodies have been encountered.

Over $2,000,000 has been spent in developing the property. An ore zone over 2,500 feet long and as much as 100 feet in width has been opened up. Ore extends to a depth of 1,400 feet but in the lower levels is of low grade. The ore is variable throughout the mine, ranging from high-grade chalcopyrite-bornite lenses to sparsely mineralized rock. Should copper return to the prices of 1925–29, the property will almost certainly be put into production.

Other somewhat similar copper deposits occur in the same region; some of these are worthy of extensive exploration.

Related deposits.—Numerous other deposits of the same general type as the Coast Copper occur on the islands and mainland of the Pacific coast at or near the intrusive contacts of the Coast Range and bordering batholiths. They are mostly in limestone, but some have replaced volcanic rocks. As a rule they consist of irregular bodies of magnetite, less commonly hematite, with associated lime-silicate minerals and remnants of country rock and disseminated grains and veinlets of chalcopyrite and pyrite, with more or less bornite and other sulphides. In some of them the sulphides are so scant that the deposits are more properly classed as iron-ore deposits. Such deposits occur at many places on Vancouver Island, particularly along the west coast.

On the northern part of Texada Island are several contact-metamorphic deposits, including both copper-bearing and iron-ore types. There is no sharp distinction between them, for the copper deposits contain magnetite, and the iron-ore deposits always carry some chalcopyrite. The country rocks are Triassic volcanics with one thick limestone band, intruded by dikes and stocks of diorite porphyrite and by larger bodies of granite or granodiorite, all related to the Coast Range intrusives. The copper deposits occur in the limestone at or near the intrusive contacts. The main copper ore bodies are irregular and consist of bornite and chalcopyrite in grains, small aggregates, and narrow bands, usually in a gangue of garnet, epidote, and diopside. The ore carries gold and silver. In only a few places is chalcopyrite present without bornite. At the old Marble Bay mine the ore ran 3½ percent or more of copper and formed a succession of irregular bodies continuing to a depth of 2,000 feet without any sign of ending. The chalcopyrite was generally in excess of the bornite, but the bornite increased in proportion with depth and appeared to be primary.

Similar deposits are known on the Queen Charlotte Islands, along the mainland coast within the Coast Range batholith, and in southern Yukon. The most productive area in the Yukon is near Whitehorse, where a great deal of ore has been mined. Over a length of 12 miles a belt of limestones and porphyrites, in sheets as much as 1,000 feet thick, has been invaded by rocks varying in composition from granite to gabbro. Near the intrusive the limestone is crystalline and is in places charged with lime-silicate minerals. In places the ore was an aggregate of silicates, such as garnet, augite, and epidote, with disseminated copper-bearing minerals and small lenses of bornite and chalcopyrite; elsewhere it consisted of magnetite masses sprinkled with grains and small masses of bornite and chalcopyrite.

Sunloch copper deposit

Location and history.—The Sunloch copper deposit is on the Jordan River near the southwest coast of Vancouver Island. It is connected by a good auto road with Victoria. The property consists of 28 claims owned by the Sunloch Mines, Ltd., organized in 1917, a subsidiary of the Consolidated Mining & Smelting Co. of Canada, Ltd. Development was active between 1916 and 1920, but little has been done since. Much surface work, a mile or so of underground work, and several thousand feet of diamond drilling were done.

Geology.—The rocks of this area belong to three formations—the Metchosin volcanics (lower Tertiary), the Sooke gabbro (middle Tertiary), and the Sooke formation (upper Tertiary). The Sunloch and adjacent mineral deposits occur at or near the contacts of a mass of Sooke gabbro which intrudes the Metchosin volcanics. The Sooke formation does not crop out in the region surrounding the mine.

The Metchosin volcanics include amygdaloids, agglomerates, flow breccias, and tuffs, all of basic composition. Near the Sunloch and adjoining claims the volcanic rocks are sheared and intruded by a considerable mass of gabbro and are so highly metamorphosed that their original character is almost obliterated. They consist of greenish and brownish hornblende, labradorite, in places augite, and small amounts of magnetite, pyrite, chalcopyrite, and veinlets of quartz, epidote, zoisite, chlorite, calcite, and sericite. The volcanic rocks were compressed into large folds striking N. 60°–70° W. and have dips as steep as 85°. The folding was accompanied by considerable fracturing in the less competent beds.

In middle Tertiary time the Metchosin formation was intruded by several stocks and dikes of coarse basic gabbro. The gabbro mass in the vicinity of the Sunloch claims is considerably altered and its original character largely obliterated. It is a black irregular-grained rock, consisting chiefly of hornblende, labradorite-bytownite, a very little augite, ilmenite, magnetite, and titanite. The augite was almost entirely altered to pale-green fibrous hornblende before the rock was noticeably fractured and invaded by mineralizing solutions. Later the gabbro was fractured and attacked by solutions which deposited great quantities of greenish-brown hornblende in veinlets cutting the feldspars, augite, and hornblende. The Sunloch mass, so far as known, has two nearly parallel boundaries about half a mile apart and is therefore to be classed as a dike rather than as a boss or stock. Its northern contact, in the canyon of the Jordan River, has a nearly vertical dip to the north. The southern contact is also nearly vertical but is less regular than the northern.

Ore deposits.—Copper deposits occur on or near both contacts of the Sunloch gabbro dike. About 300 feet from the northeast contact are several ore bodies of the Sunloch group. Where the southwestern contact crosses the Jordan River there are several showings on the Vulcan group of claims, and where it reaches Sinn Fein Creek are the showings of the Black Hornet claim.

The structure of the country rocks has largely determined the location of the ore bodies. The bedding near the deposit strikes N. 60°–90° W. and dips 60°–90° N. The probable axis of the gabbro intrusion is parallel in general to the folding in the basalts. The Sunloch gabbro mass, however, in the vicinity of the deposits, strikes N. 50° W. and therefore cuts the bedding planes at about 30°. A pronounced schistosity has been developed close to and parallel to the contacts of the gabbro. The basalts are also cut by a series of faults striking N. 10°–40° E., nearly normal to the strike of the bedding. These faults are all small, with throws of only a few feet. Two persistent sets of closely spaced joints are also present in the tunnels, one striking N. 30° W. and dipping 80° NE. and the other striking N. 55° E. and dipping 83° NW. The schistosity exercised the greatest control over the mineralization and determined the locations of the largest and most promising ore bodies, but the bedding also was a factor in the location of smaller deposits. Because of the irregularity of the schistosity the ore bodies are also irregular in size and trend.

The ore is a sheared and hornblenditized rock containing either a large proportion of finely disseminated chalcopyrite or a smaller amount of chalcopyrite distributed in a network of small, filmy veinlets. Veinlets either of quartz and epidote carrying pyrite and chalcopyrite or of aplitic material occur locally. A banding in the deposit is produced by alternating layers of rich and lean ore. The ore is invariably granular, and large masses of pure sulphides are rarely seen. Small grains of pyrite are plentifully scattered throughout the ore. The complete list of minerals in the Sunloch ore, in the order of their deposition, comprises magnetite, hornblende, aplite, quartz, epidote, pyrite, molybdenite, chalcopyrite, limonite, and chalcocite. The chalcocite is probably supergene and of recent origin. It occurs only in small quantities.

There are three ore zones roughly parallel and about 300 feet apart. The most southerly, the Cave zone, lies about 400 feet north of the gabbro contact; the most northerly is the River zone, and between them are the Archibald showings. The River zone has been most extensively developed. It crops out at several places near and north of the portal, on the same side of the river. A drift along the ore body shows a large body of 3 to 4 percent copper ore with a little gold. A crosscut 240 feet from the portal exposed 15 or 16 feet of ore averaging 3.7 percent of copper, and diamond drilling has proved the continuation of the zone 150 feet below the workings.

The Cave ore zone is more irregular and more difficult to follow and outline. The tunnel began on a good surface showing and was driven 180 feet S. 75° E. The first 60 feet averaged 4 percent of copper. At 180 feet from the portal a southerly crosscut was driven for 190 feet. The first 60 feet of the crosscut was in low-grade ore averaging 0.9 percent copper, though 10 feet averaged 1.3 percent. The next 20 feet was unmineralized, and beyond this was 36 feet of ore averaging 2.58 percent, one section of which averaged 5.1 percent for a distance of 11 feet. The remainder of the crosscut passed through low-grade ore. The rich streak encountered in the crosscut was drifted on for 200 feet, mostly through good ore.

The Archibald showings were discovered about midway between the River and Cave zones, at an altitude of 260 feet above the levels of the tunnels. A diamond-drill hole connecting the tunnels underneath these showings proved the presence of 2 feet of 4 percent ore and some low-grade material. A crosscut from the river tunnel to this ore encountered better ore than was inferred from the drill cores.

At the end of 1918 it was estimated that 100,000 to 150,000 tons of ore averaging 3 percent of copper had been proved. The work of the next two years materially increased this amount.

On the Gabbro group of claims occur chalcopyrite-bearing zones like those on the Sunloch group.

Drum Lummon mine

Location and history.—The Drum Lummon mine is about 100 miles southeast of Prince Rupert, about 4,000 feet from the shores of a small bay on the west side of Douglas Channel. It is about 26 miles from Hartley Bay, at the entrance to Douglas Channel, the nearest port of call on the steamboat route between Prince Rupert and Vancouver.

Work on the property was begun in 1915 by the Drum Lummon Copper Mines, Ltd. In 1919 and 1920, 355 ounces of gold, 1,281 ounces of silver, and 59,559 pounds of copper were produced, but for various causes the production was made at a loss. In 1921 the company was reorganized as the Drum Lummon Mines, Ltd., and work was carried on until May, 1923. In 1925 the Paisley Point Mines was organized to work the property, but only a little development work was done. In the fall of 1928 the Los Angeles-Vancouver Mines, Ltd., took over the property from the Paisley Point Mines and worked it until September, 1930, when the mine was closed down.

Geology.—The property is within the Coast Range batholith, which is here a quartz diorite cut by dikes and irregular masses of pegmatite. Along the contacts of the pegmatite dikes and locally as far as 100 feet from the pegmatite the quartz diorite is altered to a fine-grained light-gray or pinkish aplitic rock. The ore occurs in the pegmatite, which consists of quartz, microcline, orthoclase, biotite, albite, and anorthoclase; the metallic minerals are chalcocite, bornite, covellite, chalcopyrite, micaceous hematite, magnetite, gold, and silver. The quartz greatly exceeds in amount all the other minerals, in places forming solid masses 40 feet wide. It is centrally situated in the dikes, with the feldspar and metallic minerals on the margins. Native gold and silver, which occur in small quantities with the chalcocite and bornite in the upper workings, are practically absent from the lower workings. The ore from the lower tunnel also shows a higher proportion of chalcopyrite than that from the upper tunnel. This suggests that the chalcocite, covellite, bornite, native gold, and silver are secondary from chalcopyrite carrying a high tenor in gold and silver.

The early development work was done on the upper tunnel, at an altitude of 575 feet above the sea. Later work consisted chiefly in crosscutting at an altitude of 239 feet to intersect the same ore. Irregular masses of pegmatite and bunches of good ore were encountered, but the erratic distribution of the ore makes it doubtful whether a sufficient tonnage can be developed to be mined profitably.

Summary

Canada is fortunate in having three large deposits of copper that will continue to produce, even with the price for that metal at 5 cents a pound. Noranda Mines is in an especially enviable position. It is at present primarily a gold mine, although its annual output of copper is over 60,000,000 pounds. With proved reserves enough to last for some 20 years, it will probably long continue to be the most stable of Canada's copper producers. In Ontario the production of copper is closely bound up with that of nickel, the only present production being from the Sudbury ores. A rise in copper prices would be followed by an increase in the copper production of the International Nickel Co., and a similar increase would take place if greater markets for nickel could be obtained. The company has reserves of nickel-copper ore to last at the present rate of depletion for over 100 years. In Manitoba the Flin Flon deposits show an operating profit, though interest is not being paid on capital investment. The property has reserves for about 15 years. A rise in the price of copper or zinc would greatly increase its revenue, but even at present prices production will be maintained. In British Columbia the outlook is less hopeful. The two producing mines, Britannia and Hidden Creek, are being operated at almost minimum capacity and at a loss in an effort to carry on until conditions improve. The Britannia has large reserves and undoubtedly will in the future, as in the past, be an important factor in Canada's copper production.

In addition to these properties, which are continuing to operate even at the low ebb of base-metal prices, there are others merely awaiting a return of better prices to reopen. In this class are several properties in the Rouyn field of northwestern Quebec, the Sherritt-Gordon of northern Manitoba, and the Copper Mountain and Coast Copper in British Columbia. Besides these properties, on which development work has proved considerable reserves, there are many prospects awaiting more exploration, and there can be but little doubt that future prospecting will reveal many more.

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Copper resources of Alaska [1]

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Introduction

Copper minerals are widely distributed in Alaska and have been reported from practically all the mineralized areas of the Territory, yet deposits that have attained economic importance through production or promise of commercial value are confined to a few districts. The most prominent districts include the Copper River district, Prince William Sound, part of southeastern Alaska, and the Nabesna-White district. Each of the first three is producing or has produced copper commercially. The relative output of the districts is in the order in which they have been named; the Copper River district (Kennecott) easily takes first place.

Copper sulphide deposits were discovered in southeastern Alaska during the Russian occupancy, and the occurrence of native copper in the Copper River Valley was also known to the Russians. Small shipments were made from Alaska before 1900, but copper mining did not really begin till after the influx of prospectors in 1897 and 1898. The smelting of copper ores from both southeastern Alaska and Prince William Sound began about 1900 and by 1907 yielded over 3,000 tons of copper a year. In 1911 the Kennecott mines came into production, and the output of copper from Alaska, stimulated by high prices and the demands of the World War, reached a peak of nearly 60,000 tons in 1916. Since that time production has decreased, and in 1932 it was about 4,350 tons.

The accompanying table shows the weight and value of copper and silver obtained from the copper mines of Alaska from 1880 to 1932.

In the following short description the principal Alaska copper-bearing districts are mentioned in the order of their total production of copper to this time. This order is convenient and also brings out differences in mode of occurrence, for to a considerable degree the deposits of the several districts are geologically unlike. Few of the copper deposits of Alaska have been studied sufficiently to justify an attempt at a genetic classification, and such an attempt will not be made here. Instead, their form and geologic relations will be used as a basis for the descriptions. The following notes on the districts or localities where copper deposits occur include the localities already mentioned and others that have not yet been productive. The districts are shown on plate 4.

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Copper and silver produced at Alaska copper mines, 1880, 1900–1932 [a]

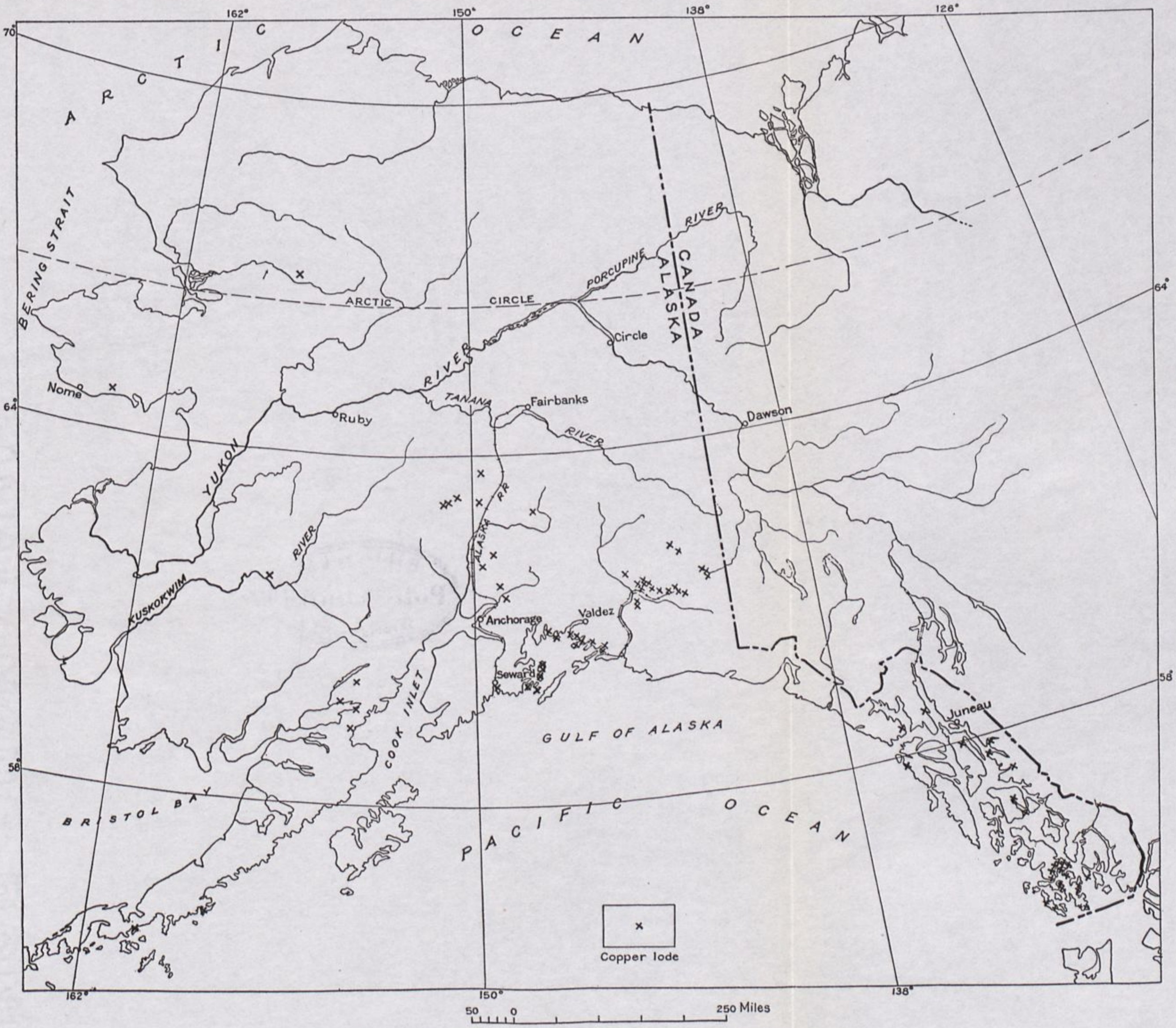
Year	Ore mined (tons)	Copper		Silver	
		Pounds	Value	Fine ounces	Value
1880	....	3,933	$826	....	....
1900	500	100,000	16,000	200	$124
1901	1,350	270,000	44,000	500	300
1902	2,750	510,000	59,000	900	477
1903	9,000	1,730,000	224,510	2,500	1,350
1904	15,000	2,843,586	376,076	4,000	2,330
1905	52,199	3,481,771	542,155	30,090	18,292
1906	105,739	6,459,803	1,246,682	27,861	18,577
1907	98,927	6,308,786	1,261,757	52,056	34,357
1908	51,509	4,585,362	605,267	33,602	17,809
1909	34,669	4,124,705	536,211	22,549	11,726
1910	39,365	4,241,689	538,695	26,388	14,250
1911	68,975	27,267,878	3,408,485	320,114	169,660
1912	93,452	29,230,491	4,823,031	376,593	231,605
1913	135,756	21,659,958	3,357,293	273,179	165,000
1914	153,605	21,450,628	2,852,934	283,355	156,695
1915	369,600	86,509,312	15,139,129	897,839	455,204
1916	617,264	119,654,839	29,484,291	1,207,121	794,286
1917	659,957	88,793,400	24,240,598	1,041,153	857,911
1918	722,047	69,224,951	17,098,563	719,391	719,391
1919	492,644	47,220,771	8,783,063	488,034	546,598
1920	766,095	70,435,363	12,960,106	682,033	743,416
1921	477,121	57,011,597	7,354,496	544,311	544,311
1922	581,384	77,967,819	10,525,655	623,518	623,518
1923	731,168	85,920,645	12,630,335	715,040	586,333
1924	761,779	74,074,207	9,703,721	572,078	383,292
1925	860,023	73,855,298	10,361,336	596,607	412,131
1926	670,000	67,778,000	9,489,000	605,190	377,600
1927	645,000	55,343,000	7,250,000	525,100	297,800
1928	579,500	41,421,000	5,965,000	350,430	205,000
1929	590,400	40,510,000	7,130,000	351,730	187,400
1930	531,000	32,651,000	4,244,600	279,990	107,800
1931	88,000	22,614,000	1,877,000	193,850	56,200
1932	56,900	8,738,500	550,500	81,150	22,900
	11,062,900	1,253,992,500	214,680,000	11,928,150	8,763,900

[a] Brooks, A. H., Alaska's mineral resources and production, 1923: U. S. Geol. Survey Bull. 773, p. 29, 1925. Smith, P. S., Mineral industry of Alaska in 1932: U. S. Geol. Survey Bull. 857-A, p. 55, 1934.

The Copper River Basin, in southern Alaska, is noted for the group of mines at Kennecott, near the east end of a copper belt that extends for many miles along the north side of the Chitina Valley. Besides the Kennecott mines, this area contains many widely known prospects, several of which have produced a little copper. The Nabesna-White district, north of the Wrangell Mountains, might be regarded as part of the Copper River district, because, although in the Tanana River drainage basin, it is reached by way of the Copper River Valley.

The Prince William Sound district, also in southern Alaska, includes many prospects, three large productive mines, and several small ones, none of which are now in operation.

Copper deposits occur in southeastern Alaska near Ketchikan and at scattered, hitherto unproductive localities near Juneau, Wrangell, and Hyder. The deposits of the south end of Prince of Wales Island, near Ketchikan, particularly those of the Kasaan Peninsula and Copper Mountain, have been the chief productive areas of this part of Alaska.



MAP OF ALASKA, SHOWING LOCALITIES WHERE COPPER DEPOSITS ARE KNOWN

Several areas hitherto unproductive yet known to have possibilities of yielding copper include the Iliamna Bay district, parts of the Susitna River region, the Kantishna district north of Mount McKinley, Prospect and Balboa Bays on the Alaska Peninsula, Unalaska Island, the Russian Mountains in the Kuskokwim Basin, the Maclaren River (a tributary of the Susitna River), and parts of Seward Peninsula and the Noatak-Kobuk region.

The limits of this paper make it impossible to include descriptions of all occurrences of copper ores in Alaska that have received notice. Certain deposits are therefore chosen to serve as examples, either because they illustrate modes of occurrence or because they have been important producers of copper ore.

Copper River Basin

The copper-bearing part of the Copper River Basin lies chiefly on the south slopes of the Wrangell Mountains and includes a narrow belt of sediments and volcanic rocks extending eastward for nearly 100 miles along the north side of the Chitina River Valley.

Native copper was used by the aborigines of the Copper River Valley for making knives, spearheads, needles, and other implements, and its occurrence thus came to the knowledge of the early Russian explorers. Active search for copper began in 1898 and soon led to the discovery of many deposits, among which were those at Kennecott and others which for a time attracted much interest. The first shipment of copper ore from Kennecott was made on the completion of the Copper River & Northwestern Railway, early in 1911, and was followed by many millions of dollars' worth of ore, chiefly from Kennecott.

The rocks most intimately associated with the copper are mainly bedded and include limestone, argillite, slate or shale, and basaltic lava flows. These rocks are cut by granular intrusives, mostly diorite or quartz diorite. The oldest group of rocks, the Strelna formation (early Carboniferous), is made up of argillite, slate, limestone, basaltic lava flows, tuff, and granular intrusives, all more or less metamorphosed. Then follow two formations of great importance in connection with the copper deposits. The first, the Nikolai greenstone (probably Permian), consists of not less than 5,000 feet of diabasic lava flows. Overlying the Nikolai greenstone is the Chitistone-Nizina limestone (Upper Triassic), which has a maximum thickness of at least 3,000 feet. This limestone is overlain by the black McCarthy shale (also Upper Triassic), which is nearly as thick as the limestone. The Jurassic and Cretaceous shale, sandstone, and conglomerate and the thick Tertiary volcanic rocks that complete the geologic column are not important in connection with the copper deposits.

The lodes may be described as (1) replacement deposits in limestone, (2) veins and disseminated deposits of copper sulphides in greenstone, (3) fissure veins in various kinds of rock, (4) contact deposits between limestone and intrusive diorite, and (5) disseminated deposits in fractured diorite. This is essentially the classification of Brooks. Copper occurs also as native copper in greenstone and in gravel deposits. By far the larger part of the copper produced in the district has come from the limestone. The fissure veins and veins in greenstone have yielded a comparatively small amount of ore, and the gold placer mines have contributed some native copper.

The source of the copper in the limestone and greenstone is of interest and practical importance, as it has a bearing on the form and extent of the deposits. Copper mineralization in both limestone and greenstone was one process, with no indication that the copper in the two formations was derived from different sources. Although the larger deposits have been found in the limestone, the wide distribution of copper in the Nikolai greenstone throughout the Chitina Valley leads to the conviction that some physical or chemical characteristic of the greenstones is accountable for the presence of the copper there, whatever may be the reason for its presence in the limestone.

Two explanations for the source of the copper have been advanced by Moffit and Mertie (9, p. 96) as having a high degree of probability, and the further suggestion is made that they may have acted together:

1. The copper was derived from the Nikolai greenstone through leaching by meteoric waters of the deeper circulation, heated and perhaps charged with magmatic products by contact with underlying bodies of hot intrusive rocks.
2. The copper was derived directly from magmatic solutions, discharged from underlying magmas in the course of intrusion, the magma being either basic and related to the Nikolai greenstone, perhaps as the underlying reservoir that supplied the basaltic flows, or else granodioritic.

In the absence of proof for either hypothesis they conclude:

> It seems best at present to regard the source of the copper in the lodes as an open question. The solutions that deposited the copper may have been either of magmatic origin or of atmospheric origin and heated by contact with bodies of hot intrusive rocks, but it is believed that, irrespective of the original source of the copper, the deposits were formed by heated water, migrating upward and being therefore classifiable in effect, at least, as hypogene solutions.

Replacement deposits in limestone are best represented at Kennecott, but they occur elsewhere in the district. They are practically restricted to the lower part of the Chitistone limestone, near but not at its contact with the Nikolai greenstone, and are formed by the replacement of the limestone along fault and other fracture planes. In the Bonanza, Jumbo, and Mother Lode mines at Kennecott the principal ore bodies have resulted from the replacement of dolomitized limestone along vertical fault and fracture planes approximately normal to the strike (N. 60° W.) of the country rock. The large ore bodies are from five to ten times as long as they are high, and their long dimension is nearly parallel to the dip of the limestone, about N. 30° E., with a pitch of about 30°. The veins thin out above and are widest at the base, where they terminate on a bedding fault about 40 feet above the limestone-greenstone contact. Thus the idealized form would be that of a thick-backed knife blade lying on the bedding plane with its thin edge up. Irregular-shaped replacement bodies, stockworks, and disseminated ores are also present. According to Bateman and McLaughlin (8) the hypogene ore minerals at Kennecott are chalcocite, covellite, enargite, bornite, chalcopyrite, luzonite, tennantite, pyrite, sphalerite, and galena. Oxidation of the ores has taken place to the lowest depth reached by the Bonanza incline, about 2,800 feet vertically below the outcrop, and has produced malachite, limonite, covellite, antlerite, azurite, arsenates of copper, chalcanthite, cuprite, and possibly brochantite. The minerals in both lists are named in the order of their abundance. It is estimated by Bateman that the sulphide ores, of which chalcocite constitutes from 92 to 97 percent, make up about 75 percent of the ores mined. Covellite forms from 2 to 5 percent of the ore minerals, and other sulphides less than 1 percent. The ores of Kennecott carry considerable silver, which is recovered in smelting. Practically no gold is present. The immense size of the ore bodies may be seen from the following description by Bateman, which was written before the full extent of the Bonanza-Mother Lode vein was revealed:

> The average height of the main Bonanza vein from the base to the apex, measured normal to the incline, is about 210 feet in the upper levels and 150 on the lower levels. It has been followed for a distance of about 1,900 feet, measured along its base, and the width varies from 2 to 50 feet. The main Jumbo vein, exclusive of its enlargement at the flat fault, averages about 360 feet in height, from 2 to 60 feet in width, and has been followed down on its base for 1,500 feet.

The ore body of the Green Butte mine, on McCarthy Creek, is similar to those at Kennecott and has yielded some high-grade ore, as has also the Eastover mine, in the Dan Creek Valley.

The copper deposits in the greenstone have the form of veins, disseminated deposits, stockworks, and amygdules or fillings of gas cavities in the lava. The Nikolai greenstone is made up of altered lava flows which are resistant and accommodated themselves to deformation partly by bending and faulting but chiefly by breaking into innumerable blocks of various sizes bounded by fracture planes whose slickensided surfaces show movement of one block on another, even where well-defined fault planes are absent. Such fractures provided most intricate channels for the circulation of mineral-bearing solutions.

Bornite, chalcopyrite, pyrite, and chalcocite are most abundant in the greenstone deposits; malachite, azurite, native copper, silver-bearing tetrahedrite (possibly in part freibergite), cuprite, covellite, and chalcanthite also occur. The associated gangue minerals are quartz, epidote, and calcite.

There are a few well-defined veins of considerable extent, both in the Strelna formation and in the Nikolai greenstone. Most of the copper deposits are of the stockwork and disseminated types. Solutions circulating through the openings of the greenstone deposited copper minerals and to a certain extent replaced the greenstone; they also penetrated the greenstone walls adjacent to the channels and deposited copper minerals that have no evident connection with the main veins, thus forming copper deposits that are notably irregular in shape and uncertain in extent.

Many copper sulphide deposits have been found in the Nikolai greenstone, of which the vein deposit of the Nugget Creek mine, in the Kuskulana Valley, was one of the most promising, but after extensive exploration and a small production the mine was abandoned.

Native copper has been found in the mines at Kennecott, but its principal occurrence is in the Nikolai greenstone, filling the vesicles of lavas or occurring with quartz as thin sheets and irregular bodies in small veins. Such a deposit is present on Shower Gulch, near the head of the Kotsina River, but the copper content has not been regarded as sufficient to justify development work.

Weathering of the greenstone has produced placer deposits of native copper, notably with gold in the gravel of Dan and Chititu Creeks, where the copper collects in the sluice boxes. It is saved from the clean-ups and shipped to the smelters from time to time. A mass of native copper 7 feet long, 3 feet wide, and averaging about 6 inches in thickness was found in the gravel of Nugget Creek, a tributary of the Kuskulana River. Smaller masses weighing 800 pounds or more have been found on Dan and Chititu Creeks.

Copper deposits of the contact type and disseminated deposits in fractured diorite occur in the Kuskulana Valley but are not of commercial grade.

Prince William Sound

Prince William Sound, an embayment of the Gulf of Alaska, is the coast terminus of two routes to the interior, the Richardson Highway from Valdez to Fairbanks and the Copper River & Northwestern Railway from Cordova to Chitina and Kennecott. It is almost shut off from the Pacific Ocean by a chain of large islands. Knight Island, Latouche Island, and various other less well-known islands are situated within it. The surrounding country is mountainous and in part heavily glaciated.

Formerly the glaciers were much more extensive, and at the time of maximum glaciation only the highest peaks of the larger islands could have risen above the ice surface. The mountains owe their present form largely to ice erosion, which is important to the miner because it stripped away any oxidized ores that may have existed in preglacial time and inhibited further oxidation while the ice persisted.

The copper deposits of Prince William Sound attracted considerable attention as early as 1897, when the properties of the Alaska Commercial Co. on Landlocked Bay, the Gladhaugh mine at Ellamar, and the Big Bonanza mine on Latouche Island were staked. Interest in the copper deposits grew rapidly after 1897 and reached its high point in 1907, when several hundred men were engaged in mining and prospecting for copper in this region and considerable capital had been invested. After 1907, however, the less favorable financial situation and the failure to develop commercial ore reduced prospecting almost to the vanishing point, and at present there is no mining of copper in the district. Only three of the many properties discovered here made any considerable production—the mine at Latouche, recently worked out and abandoned; the mine at Ellamar; and the Midas mine, near Valdez.

The rocks of Prince William Sound are dominantly sedimentary but locally include greenstones of extrusive and intrusive origin and a few relatively small masses of granite. Light-colored porphyritic dikes, probably related to the granite, are numerous in the northern part of the district. The sediments are in the main closely folded graywacke and slate showing more intense metamorphism on the north and west sides of the sound than on the east side and on the large islands of the south side. Conglomerate is interstratified with the slate and graywacke in a few places, but limestone is almost lacking. The graywackes in some places grade into feldspathic sandstone. The greenstones are of special interest because copper occurs in or near them. This association, like that in the Chitina Valley, strongly suggests a genetic relation between the copper and the volcanic rocks, but it does not follow that the same relation holds in the two districts. The greenstones include lava flows, tuffs, agglomerates, and subordinate dikes, sills and larger intrusive masses of less regular form almost contemporaneous with the associated sediments. Greenstones are especially abundant at Knight Island and in the vicinity of Landlocked and Boulder Bays, where surficial volcanic rocks were especially developed. The intrusive greenstones occupy less area but are more widely distributed.

The age of the rocks of Prince William Sound is not fully known. The sediments are in part Upper Cretaceous but may include older beds. The intrusives are in part Cretaceous or post-Cretaceous and may be as late as post-Eocene.

The copper deposits are simple in form and in mineral composition, and all with the possible exception of a few in the vicinity of Cordova belong to one general type. They consist chiefly of chalcopyrite, pyrite, and pyrrhotite, deposited along fault planes in fault zones or disseminated through the adjacent country rock. Ordinarily the deposits include both veins and disseminated sulphides. The veins are tabular or lenticular; the disseminated bodies are irregular in form and variable in copper content. As a rule the boundary between disseminated sulphides forming ore and waste is determined only by assay, for the sulphide content ordinarily varies inversely with the distance from the more open channels, and the ore grades finally into barren rock. The sulphide bodies or veins along the fault planes probably in part fill open cavities but may be much more largely formed by the replacement of particularly susceptible beds or of wall rock and fault breccia. The location of most of the ore bodies is evidently dependent on faults.

The deposits of Prince William Sound show only surface oxidation. Enrichment or impoverishment of the deposits through alteration by surface waters has not been recognized. If an oxidized zone were ever present, it was completely removed from all the known ore bodies during the regional glaciation, and the time since the retreat of the ice has not been long enough to produce a new oxidized zone. This condition contrasts strongly with that at Kennecott, where much of the ore from the lowest levels is carbonate, probably resulting from pre-Pleistocene oxidation.

The usual minerals in the copper deposits of Prince William Sound are pyrite, pyrrhotite, chalcopyrite, chalmersite (cubanite), sphalerite, galena, and quartz. Gold and silver are present in varying amounts. In a few prospects near Cordova chalcocite is more abundant than chalcopyrite and is accompanied by a little native copper. Chalcopyrite and chalmersite (cubanite) are the only copper minerals of present or probable future commercial importance in the typical deposits. Chalmersite, usually regarded as a rare mineral, is widely distributed in the region. Nickel has been reported from the copper deposits at four or five localities.

The country rock at Ellamar is predominantly soft black slate with interbedded black limestone, dark argillite, and a few beds of fine-grained graywacke. No igneous rocks are known nearer than the greenstone lavas north of Gladhaugh Creek, nearly half a mile away. The ore body consists of two parts—(1) a large lens of solid pyrite, forming the hanging wall for (2) smaller, closely packed parallel lenses of other sulphides. Polished specimens studied by B. L. Johnson showed chalcopyrite (predominant), chalmersite (cubanite), pyrrhotite, pyrite, sphalerite, and specks of galena (?). Although the Ellamar mine was operated primarily because it provided a base ore desired at the smelter, it yielded also a large amount of gold in the later years of operation.

Several smaller copper deposits in the vicinity of Ellamar, especially that of the Threeman Mining Co. on Landlocked Bay, formerly produced high-grade shipping ores.

The country rock of the Beatson mine, at Latouche, is chiefly interbedded slate and graywacke, with graywacke predominating. Minor rocks notable in the mine are (1) a green chloritic schist, which caves badly in mining; (2) a very hard cherty rock, which crosses the bedding of the slate and graywacke irregularly and appears to be an alteration product of the country rock; (3) a dark basic dike resembling graywacke and composed of alteration products of olivine in a matrix of calcite, chloritic material, and sericite. Bateman (20) found pyrite, pyrrhotite, chalcopyrite, chalmersite (cubanite), sphalerite, and galena in the Latouche ore, associated with a gangue of quartz and a little siderite (ankerite?). Chalcopyrite (about half) and pyrrhotite and pyrite (each about a quarter) are the dominant sulphides. Sphalerite is widely distributed in small quantity; chalmersite is rare. In the later years of production the ore mined was of very low grade, but skillful management and efficient operation made mining profitable.

The Midas mine, on Solomon Gulch near Valdez, includes two ore bodies in a broad band of black slates intruded at several places by small bosses, sills, and dikes of greenstone. Interbedded with the black slate are argillite, chert, graywacke, and quartzite. The ore occurs in mineralized shear zones, partly as the result of replacement and impregnation of the crushed country rocks and partly as a cement for the crushed rock. The sulphides are pyrite, chalcopyrite, pyrrhotite, and sphalerite in a gangue of quartz. This mine has produced considerable ore and although closed for many years is not exhausted.

At Rua Cove, on the east side of Knight Island, a copper deposit occurs along a fault zone traversing a complex of greenstone and cherty or quartzose rock (probably altered sediments) and consists principally of pyrrhotite with chalcopyrite. Although intensively explored, this deposit has not yet been brought to a producing stage.

The similar mineral assemblages of the copper deposits of Prince William Sound and their common association with certain kinds of igneous rocks suggests the probability of their common age and origin. The time of this mineralization is not known but was probably either the period of mountain building and intrusion in Cretaceous or early post-Cretaceous time or that in post-Kenai (Eocene) time.

Southeastern Alaska

The copper deposits of southeastern Alaska, though widely scattered throughout the archipelago, are most numerous in the islands west of Ketchikan. The Ketchikan copper district, embracing the deposits of the south end of Prince of

Wales Island, Dall Island, and Gravina Island, includes the largest and only productive deposits and will therefore receive most attention.

Southeastern Alaska presents a complex of geologic formations and a complicated geologic history, which is only partly understood. The mountains of the mainland are largely the granitic and dioritic intrusive rocks of Upper Jurassic or Lower Cretaceous age, which compose the great Coast Range batholith. The islands to the west are made up of sediments of many kinds interbedded with volcanic rocks and cut by numerous intrusives. These rocks for the most part are much altered and range in age from probable pre-Ordovician through all the periods of the geologic time scale to the Quaternary.

The islands near Ketchikan exhibit a variety of sediments—graywacke, slate, conglomerate, limestone, and chert—together with tuffs and lava flows and large masses of granular igneous rocks ranging from basic varieties like dunite and pyroxenite to acidic types such as granite, although quartz diorite and granite predominate. Most of the copper deposits were incidental products of the intrusion.

The copper deposits of southeastern Alaska may be classified (26) as contact deposits, fissure veins, replacement veins and impregnation zones, shear-zone deposits, and deposits that are unusual and difficult to assign to any definite category. Many contain valuable metals other than copper. Gold is almost invariably present and accounts for a large part of the value of the ore in some of the mines.

The contact deposits are most widely developed on Kasaan Peninsula and at Copper Mountain, near the head of Hetta Inlet, at or near the contact of such bedded rocks as limestone, graywacke, greenstone tuff, and schist with intrusive granitic masses. Most of the ore bodies at these localities consist essentially of magnetite, chalcopyrite, and pyrite, but some contain little or no magnetite. In one the ore is chalcopyrite and pyrrhotite; in another, chalcopyrite and pyrite with associated garnet, epidote, and hematite. As a rule the ore minerals are unevenly distributed, and mining operations are selective. As examples of this class Buddington (26) lists the Mount Andrew, Mamie, Poorman, and It mines, on the Kasaan Peninsula; one of the Rush & Brown mines at the head of Karta Bay, near the base of the peninsula; and the Jumbo and Copper Mountain mines, of Hetta Inlet, on the west side of Prince of Wales Island. The Kasaan Peninsula and Hetta Inlet or Copper Mountain localities differ chiefly in the smaller proportion of magnetite at Copper Mountain, although magnetite-chalcopyrite ores are also present nearby. The contact deposits are masses of low grade and are irregular in distribution as well as in form. Their utilization is dependent on low mining costs.

The fissure veins occur in both intrusive and invaded rocks and show no apparent relation to the contacts. They are quartz veins with chalcopyrite as the principal copper mineral but also contain pyrite, sphalerite, tetrahedrite, and galena and carry gold and silver. Commercially valuable deposits of this type are less common than the magnetite-chalcopyrite contact deposits. Examples are the Cimru property, on the north arm of Moira Sound, and deposits on the south end of Gravina Island and at the head of Port Houghton, near Juneau.

The replacement veins and impregnation zones consist in part of tabular or nearly tabular veins or bedded deposits in the rock adjoining fractures. This class merges with deposits formed by replacement or impregnation along shear zones. Its only representative among the copper deposits is at Point Astley, on Holkham Bay, southeast of Juneau.

Shear-zone deposits are found in zones of finely foliated crushed rock. The crushed rock is either replaced in part or contains closely spaced, generally tabular veins parallel to the foliation. According to Brooks (1, pp. 17–18),

> The shear-zone deposits follow zones of fracture parallel to the schistosity of the country rock. They are found . . . primarily in greenstone schist, graywacke, and sheared diorite. There are two phases of the shear-zone deposits. One consists of lenses or tabular deposits, made up largely of rich massive sulphide minerals. These have well-defined walls and are not unlike the cupriferous quartz veins. . . . The other phase consists of disseminated deposits in which the sulphides are distributed through wide zones of sheared country rock, generally without well-defined walls. In some of the disseminated deposits the sulphide mineralization is rather evenly distributed through the entire mass, which may thus be a large body of low-grade ore. More commonly, however, the mineralization is concentrated along certain zones determined by the intensity of the shearing. . . . Examples of the shear-zone deposits, including both the concentrated and disseminated phases, are found at the Rush & Brown mines, on Karta Bay; at Niblack Island; at the Corwin and Red Wing properties, near Hetta Inlet; and on Big Harbor (Trocadero Inlet), on the west side of Prince of Wales Island; and on McLeod Bay, Dall Island.

Deposits not readily classified with the foregoing types include the nickel-copper deposits of Chichagof and Baranof Islands and the palladium-copper deposits of the Salt Chuck mine, at the head of Kasaan Bay, both in gabbroic and highly ferromagnesian igneous rocks. The copper-nickel deposits have not been productive, but the palladium-copper deposit, although now inactive, has been mined for both metals.

The platinum group of metals was not at first recognized in the Salt Chuck mine, and it was operated as a copper mine, but it was later discovered that the platinum metals present were of greater value than the copper, and thereafter the ore was mined primarily for its palladium content. The country rock at the Salt Chuck mine is in general a pyroxenite (25), with gabbroic and gabbro-pegmatite phases. It is a magmatic differentiate from an intrusive rock which normally is a diorite, low in quartz and orthoclase feldspar. The ore minerals consist of copper sulphides, in grains and small patches forming ore shoots in the pyroxenite. Bornite is the chief copper mineral, but a little chalcopyrite also occurs locally. Chalcocite and covellite are present as alteration products of the bornite and chalcopyrite. Finely disseminated chalcocite and native copper occur in some drifts. Practically no gangue minerals are found with the ore. In addition to copper, gold, silver, palladium, and platinum are recovered.

The deposits near Hyder, at the head of Portland Canal, are primarily gold-silver deposits but contain copper, lead, and zinc also. Copper occurs (1) in a low-grade disseminated ore forming roughly tabular lodes in greenstone, tuff, or tuffaceous conglomerate that contain dominantly pyrite, chalcopyrite, sphalerite, and galena with locally a high content of gold or silver; and (2) in quartz fissure veins in granodiorite and in sedimentary and volcanic beds. The ore shoots consist largely of galena and pyrite with locally associated tetrahedrite, chalcopyrite, pyrrhotite, a little sphalerite, and native gold (26, pp. 357–358). The base-metal ores also occur in fissure veins.

Deposits on Kupreanof Island, at the head of Duncan Canal, are the only developed copper properties in the Wrangell district. The ore bodies consist of cupriferous pyrite or chalcopyrite in masses of pyrrhotite in a series of black slate and phyllite interbedded with chert and greenstones. The greenstones appear to include dikes and sheets of diorite, andesite flows, and probably contact-metamorphosed limestone beds. The mineral paragenesis is characteristic of many contact deposits. Buddington (26) suggests that the ore bodies were formed through metasomatic replacement of a limestone bed, and if so they might be classified with deposits of the replacement vein type.

Nabesna-White district

The Nabesna-White district includes the headwaters of the Tanana and White Rivers, which rise on the east slopes of the Wrangell Mountains. Access to this district is obtained through the Copper River Valley and is still difficult, although a branch of the Richardson Highway was recently extended to the Nabesna River. Copper occurs in association with basaltic lava flows and as contact deposits resulting from igneous intrusion. No producing mines have been developed.

At Orange Hill, near the foot of the Nabesna Glacier, irregular bodies of low-grade auriferous copper ore, bornite, and chalcopyrite, associated with garnet, calcite, epidote, hematite, and a little molybdenite, have been found. The deposits lie in the contact zone of limestone and intrusive diorite. Extensive magnetite bodies likewise reported to carry gold are found nearby. At White Mountain, a few miles northwest of Orange Hill, the gold lode of the Nabesna Mining Corporation is at a similar contact of diorite and limestone.

Native copper occurs as nuggets in the gravel of many streams, particularly the tributaries of the Chisana and White Rivers, which drain areas of amygdaloidal bedrock. It occurs as an oxidation product in the surface croppings of sulphide deposits in the amygdaloids associated with cuprite, malachite, chalcocite, chalcopyrite, and calcite and in places with zeolites. Near the head of the Middle Fork of the White River native copper of primary origin occurs in a definite lava sheet intergrown with prehnite, calcite, and zeolites. Large masses of native copper have been found on the White River near the international boundary.

Other localities

The districts previously described have been either productive or intensively prospected. Other less thoroughly investigated localities are mentioned below.

The Iliamna district, on the west side of Cook Inlet, embraces a region of gneiss, schist, and metamorphosed limestone intruded by granitic rocks. The deposits may be referred to two classes—chalcopyrite deposits in limestone, with or without associated contact minerals, and chalcopyrite in quartz veins in greenstone and granite (29). Only the deposits in limestone have shown prospective value. They contain chalcopyrite associated with pyrite, garnet, epidote, magnetite, hematite, and quartz in deposits close to and parallel with igneous contacts. None of the deposits have been developed to the producing stage.

Deposits containing pyrite, galena, sphalerite, chalcopyrite, and quartz in shear zones in volcanic rocks have been found near Prospect and Balboa Bays, on the Alaska Peninsula (30). Copper is also reported on some of the Aleutian Islands, but nothing is known of its occurrence.

Copper occurs at many localities in the Susitna River Basin, generally associated with limestone or ancient volcanic rocks. In the Talkeetna Mountains (31) andesitic lavas and subordinate limestone beds are intruded by great masses of granitic rocks, with which copper, gold, and other ores are apparently genetically connected. The copper-bearing lodes are found in shear zones cutting the volcanic rocks and contain chalcopyrite, pyrite, bornite, and arsenopyrite.

Deposits containing arsenopyrite, pyrite, sphalerite, chalcopyrite, pyrrhotite, stibnite, and galena occur in the upper Chulitna Valley (32) as disseminated replacement deposits along fracture zones in limestone or less commonly in tuffs and cherts.

Deposits containing copper are reported to occur near the head of the Maclaren River, an upper tributary of the Susitna River (33).

Along the north side of the Alaska Range in the Kantishna region (34) there are several deposits in which chalcopyrite and its oxidation products are associated with pyrrhotite, sphalerite, galena, garnet, and manganese oxide.

A copper-bearing quartz lode in the Russian Mountains, 12 miles from Kolmakoff, on the Kuskokwim River (35), contains chalcopyrite and arsenopyrite with gold and silver.

Test shipments of ore carrying chalcopyrite and bornite with oxidation products were made from impregnated zones along or near limestone-schist contacts in the Seward Peninsula (36, 37).

In the Noatak-Kobuk region (38), northern Alaska, lodes containing bornite, chalcopyrite, galena, and pyrite in zones of brecciation in limestone occur but owing to their remoteness have received little attention.

Conclusion

It is evident from the preceding summary that Alaska possesses widely distributed and promising copper deposits, yet many have not been fully developed nor even investigated with sufficient thoroughness to determine their possible value. Some have yielded copper, and a few have been entirely exhausted, but under present economic conditions it is unlikely that those of lower grade or unproved possibilities will be exploited for their copper in the near future, unless association with other valuable metals will make recovery of the copper profitable.

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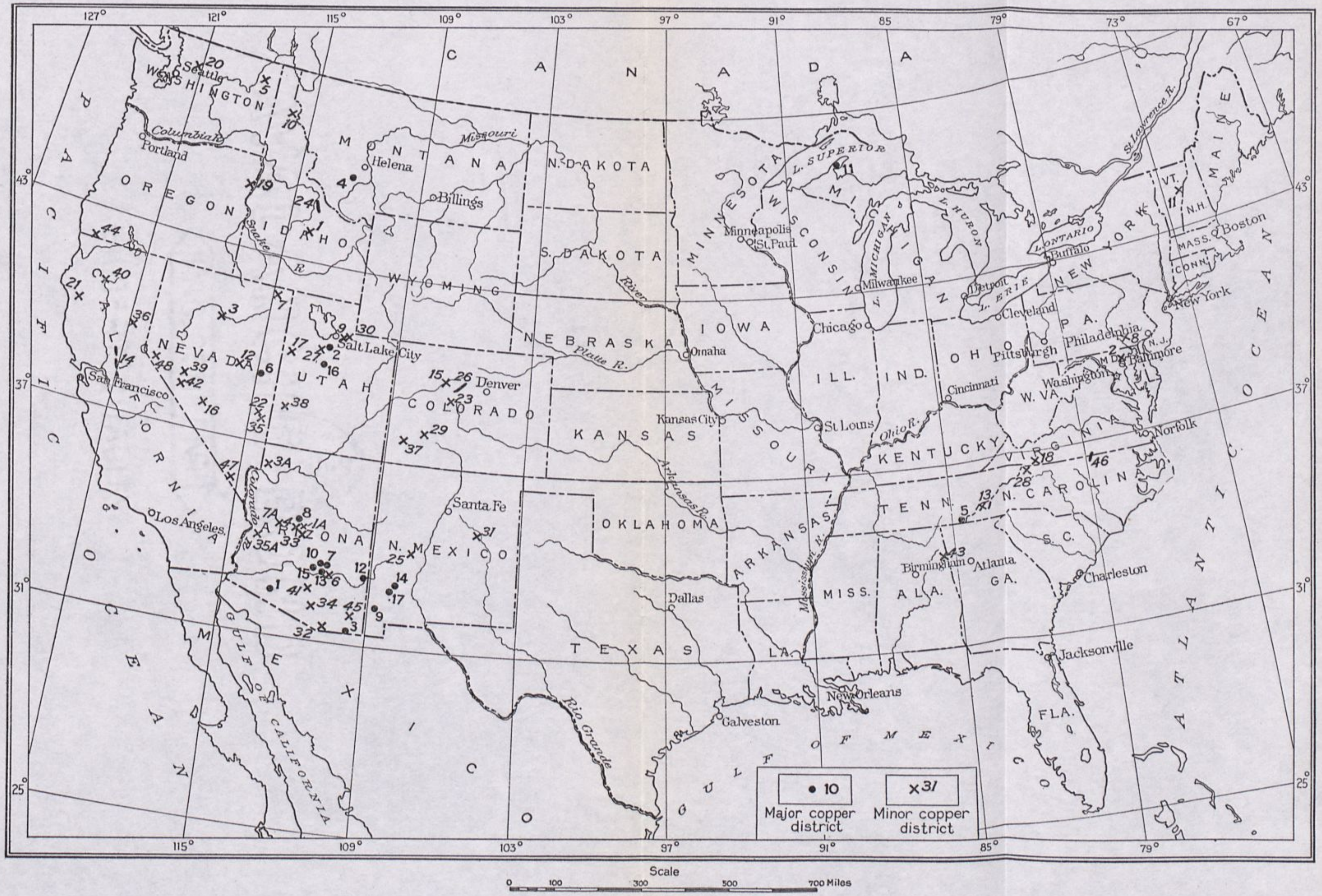

THE COPPER DEPOSITS OF THE UNITED STATES

Major districts

1. Ajo, Arizona
2. Bingham, Utah
3. Bisbee, Arizona
4. Butte, Montana
5. Ducktown, Tennessee
6. Ely, Nevada
7. Globe, Arizona
8. Jerome, Arizona
9. Lordsburg, New Mexico
10. Miami, Arizona
11. Michigan
12. Morenci, Arizona
13. Ray, Arizona
14. Santa Rita, New Mexico
15. Superior, Arizona
16. Tintic, Utah
17. Tyrone, New Mexico

Minor districts

1A. Agua Fria, Arizona
1. Alder Creek, Idaho
2. Bare Hills, Maryland
3. Battle Mountain, Nevada
3A. Bentley, Arizona
4. Bigbug, Arizona
5. Chewelah, Washington
6. Christmas, Arizona
7. Contact, Nevada
7A. Copper Basin, Arizona
8. Cornwall, Pennsylvania
9. Cottonwood-American Fork, Utah
10. Coeur d'Alene, Idaho
11. Ely, Vermont
12. Eureka, Nevada
13. Fontana, North Carolina
14. Foothill belt, California
15. Gilman, Colorado
16. Goldfield, Nevada
17. Gold Hill, Utah
18. Gossan Lead, Virginia
19. Homestead, Oregon
20. Index, Washington
21. Island Mountain, California
22. Jackrabbit, Nevada
23. Leadville, Colorado
24. Lemhi, Idaho
25. Magdalena, New Mexico
26. Northeast mineral belt, Colorado
27. Ophir, Utah
28. Ore Knob, North Carolina
29. Ouray, Colorado
30. Park City, Utah
31. Pastura, New Mexico
32. Patagonia, Arizona
33. Peck, Arizona
34. Pima, Arizona
35. Pioche, Nevada
35A. Planet, Arizona
36. Plumas County, Nevada
37. Rico, Colorado
38. San Francisco, Utah
39. Santa Fe, Nevada
40. Shasta County, California
41. Silver Bell, Arizona
42. Silver Star, Nevada
43. Stone Hill, Alabama
44. Takilma, Oregon
45. Turquoise, Arizona
46. Virgilina, Virginia–North Carolina
47. Yellow Pine, Nevada
48. Yerington, Nevada

Copper deposits in the eastern United States[1]

By Clarence S. Ross

United States Geological Survey, Washington

History

Earliest discoveries

Copper mining in eastern America has had a long and interesting history, and at one time the mines contributed materially to the mineral wealth of the country. Although mining was not extensive in colonial days, it was intimately connected with the early history of the colonies and with the commercial policy of the home government, which attempted to restrict the smelting if not the mining of ores.

The exact date of the first discovery of copper in this region is not recorded. However, copper was mined by Dutch settlers prior to the British occupation of the region in 1664—at least as early as 1650.

At least three mines that were opened by the Dutch are mentioned in the records. One was at Ellenville, Ulster County, New York; one at Bowman's Hill, south of New Hope, Bucks County, Pennsylvania; and another at Menisink, Warren County, New Jersey, 9 miles above the Delaware Water Gap. The ore was shipped to Holland for treatment, and that from Menisink was hauled by wagon to the Hudson River over the first extensive highway built in the country, but with the British occupation of New York in 1664 this outlet was closed.

Figure 12 shows the location of the copper deposits in the Eastern States, numbered as follows:

1 Capelton, Quebec.
2 High Falls, St. Lawrence County, New York.
3 Milan mine, Coos County, New Hampshire.
4 Gardners Mountain, Grafton County, New Hampshire.
5 Corinth mines, Orange County, Vermont.
6 Ely or Copperfield mine, Orange County, Vermont.
7 Elizabeth, Copperas Hill, Orange County, Vermont.
8 Blue Hill mines, Hancock County, Maine.
9 Davis mine, Franklin County, Massachusetts.
10 Simsbury (Newgate) mine, Hartford County, Connecticut
11 Bristol mine, Hartford County, Connecticut.
12 Mount Carmel, New Haven County, Connecticut.
13 Ellenville, Ulster County, New York.
14 Menisink, Warren County, New Jersey.
15 Schuyler mine, Arlington, Hudson County, New York.
16 Mines near Plainfield, New Jersey.
17 American mine, Watchung Mountain region, Somerset County, New Jersey.

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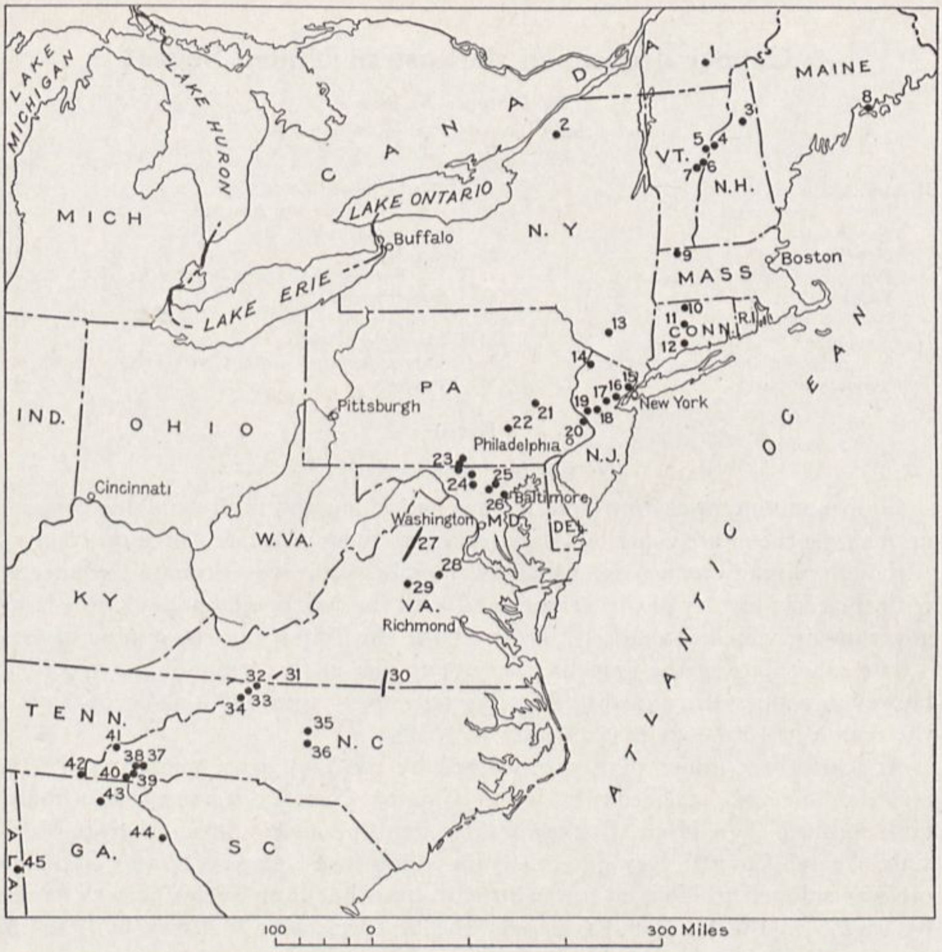

FIGURE 12.—Copper deposits of the Appalachian region.

18 Griggstown mine, near Rocky Hill, New Jersey.
19 Flemington mines, Hunterdon County, New Jersey.
20 Mine near New Hope, Bucks County, Pennsylvania.
21 Carpenter mine, Warren County, Pennsylvania.
22 Cornwall iron mine, Lebanon County, Pennsylvania.
23 Copper prospects, South Mountain region, Pennsylvania and Maryland.
24 Western or Frederick County copper belt, Maryland.
25 Mineral Hill and Sykesville, middle copper belt, Maryland.
26 Bare Hills, Baltimore City, Maryland.
27 Blue Ridge copper region, Virginia.
28 Valzinco mine, Spotsylvania County, Virginia.
29 Stony Point mine, Albemarle County, Virginia
30 Virgilina district, Virginia-North Carolina.
31 Gossan Lead, Carroll County, Virginia.
32 Peachbottom, Alleghany County, North Carolina.
33 Ore Knob, Ashe County, North Carolina.
34 Elk Knob, Ashe County, North Carolina.
35 Conrad Hill, Davidson County, North Carolina.
36 Gold Hill, Rowan County, North Carolina.
37 Wayhutta, Jackson County, North Carolina.
38 Cullowhee, Jackson County, North Carolina.
39 Savannah, Jackson County, North Carolina.
40 Otto mine, Macon County, North Carolina.
41 Fontana mine, Swain County, North Carolina.
42 Ducktown district, Tennessee.
43 Dahlonega, Lumpkin County, Georgia.
44 Magruder, Lincoln County, Georgia.
45 Stone Hill, Cleburne County, Alabama.

New England

A copper mine was opened by Governor Endicott, of Massachusetts, in 1651, but little is known of its history.

Copper mining began in Connecticut with the mine at Simsbury, chartered in 1709 and operated for about 60 years. It was then acquired by the State and used as a prison for about an equal period of time and thus gained the name "Newgate mine." It was operated again for a period beginning in 1830. The Bristol mine, about 25 miles north of New Haven, was actively operated between 1847 and 1854 and was the most productive in the State.

Copper was discovered at the Copperfield or Ely mine, in Orange County, Vermont, about 10 miles west of the Connecticut River, in 1820, and the mine was operated in a small way till 1853, when active mining began. The period of maximum production was between 1870 and 1890, when the output reached 7,500,000 pounds of copper a year. In 1793 the Elizabeth mine, which lies on the same mineralized belt at Copperas Hill, about 10 miles south of the Ely mine, began to produce pyrrhotite, which was used in the manufacture of copperas. Mining for copper at the Elizabeth began in 1830. The Union and Eureka mines, about 11 miles north of the Ely mine, form another group on the same mineralized zone. The mines in this zone during their period of greatest activity were the largest copper producers in the country. They continued intermittent production up to 1919, but all have been closed since that time.

New York and New Jersey

No mines are operated primarily for copper in New York, but the pyrite mines of St. Lawrence County have produced some copper.

The Arlington or Schuyler mine, about 1 mile north of Arlington, New Jersey, and 8 miles west of New York City, was discovered by a negro slave of the Schuyler family in 1719 and was operated intermittently until about 1850. This is interesting as the place where the first steam engine in America was used. A group of mines, of which the American was the largest, occur in the Watchung Mountain region. Most of these mines lay along the south and east fronts of First Mountain from a point a few miles north of Somerville to the vicinity of Plainfield, but a few lay north of First Mountain. Other mines were the Griggstown mine, near Rocky Hill, and the Flemington mine, near Flemington. Ores were shipped to the smelters from several of these localities, and at others smelters were built and briefly operated on local ores. Of all these mines only the Schuyler seems to have achieved any degree of success, and that only in early years, when the price of copper was high and the cost of labor very low.

Pennsylvania and Maryland

No commercial copper deposits have been found in Pennsylvania, but the South Mountain area, lying west of Gettysburg and extending into Maryland, has been prospected from time to time throughout most of the past century. Minor deposits of copper are associated with the Triassic traps in the southeastern part of the State, and small amounts have been found near New Albany, in Bedford County, where the copper occurs in gray shale of Devonian age.

The discovery of copper in Maryland is reported in a letter from Philemon Lloyd to Lord Baltimore in 1722. Many of the veins of the State appear to have been traced during the 18th century, and some mining was done before the Revolution. In 1815 a copper rolling mill was established on the Gunpowder River that used ores produced in the State. Active mining began about 1835, and this led to the establishment of smelters in Baltimore and eventually made that city a smelting center.

The copper mines of Maryland fall into three belts—one in eastern Frederick County, one in southeastern Carroll County, and one not far north of Baltimore. In the western area (Frederick County) the New London, Liberty, Dolly Hyde, and Union mines were formerly extensively operated but were finally closed in 1914. In the middle belt (Carroll County) the Sykesville mine was opened in 1849 and abandoned in 1868, and the Mineral Hill mine, first worked before the Revolution, was reopened in 1849 and worked till 1890. The principal mine north of Baltimore was at Bare Hills, which was opened in 1845 but was little worked till 1860–64 and then intermittently until 1880.

The mode of origin of the secondary ores was rather clearly understood at an early date. Thus in discussing the Maryland copper mines in 1839, Ducatel (3) described the origin of the secondary ores in the following words:

> It is probable that they originally existed as a vein of copper pyrites (sulphurets of copper and iron) with oxide of manganese in quartz, and intersecting a limestone rock. Under the influence of decomposing agents—atmospheric waters chiefly—there have been produced oxides of iron and manganese, sulphate of lime, and carbonate of copper, leaving traces of the original copper pyrites, with detached masses of limestone.

Virginia

Copper is reported to have been mined in Orange County, Virginia, before the Revolution and shipped to England for treatment. Nuggets of native copper have been found in the northern Blue Ridge and adjacent Piedmont region since the first settlement of the region and were no doubt known tc the Indians prior to that time. This has led to much prospecting in an area that extends southward from Front Royal for about 60 miles. Several hundred thousand dollars has been spent at some localities, but no commercial deposits have been found.

The extensive mining of copper in Virginia began with the discovery of the rich secondary ores of the Gossan Lead, in Carroll and Grayson Counties, in the Blue Ridge region of the southwestern part of the State, in 1854. The mines were far from a shipping point, and the ores were hauled long distances over very poor mountain roads but are reported to have run 25 percent in copper, which then commanded a high price. A great group of mines was soon developed, but with the exhaustion of the secondary ores and penetration of the lean primary sulphides it became evident that these were of too low grade for successful mining. Practically all mining ceased with the outbreak of the Civil War, but one mine on the Gossan Lead has long been producing pyrrhotite for use in the manufacture of sulphuric acid.

The Virgilina copper district, lying in Halifax County, Virginia, and Granville and Person Counties, North Carolina, in the Piedmont region of these States, was first opened in 1856. Some work was done in 1886–87, but active prospecting began in 1897 and continued until about 1904. No great production was attained, although the High Hill mine is reported to have produced 167,000 tons of 15 percent ore in 1904.

North Carolina

Gold is reported to have been discovered in North Carolina in 1799, and soon thereafter copper was found in some of the gold-bearing veins of the southern part of the State. In 1824 copper was discovered at Gold Hill. The first attempt at copper mining appears to have been made at the Fentress mine, in Guilford County, but the venture soon succumbed to promotion schemes, and operation ceased in 1856.

The discoveries of copper in the Ducktown region, Tennessee, in the early fifties of the last century, led to the so-called "copper mania" of the period and the intensive prospecting of every gossan in the region—indeed, of every rusty-looking outcrop. During this time many copper veins were located in western North Carolina and adjoining States, and at many of them experimental smelters were erected at one time or another. The Ore Knob mine of North Carolina and the Gossan Lead of Virginia were among the few mines outside of the Ducktown district that proved valuable.

The Ore Knob deposit, in Alleghany County, northwestern North Carolina, was discovered during this period but was not actively developed until the seventies and eighties of the last century, when the mine became an important copper producer. Some of the primary ores were richer than those at Ducktown, and so mining continued after the secondary ores were exhausted, but it stopped in the later eighties.

In 1875 Olcutt (10) recognized a relation between the character of the gossan at the Ore Knob mine and the copper content of the underlying primary ores and the origin of the secondary ores through enrichment. He says:

> The character of the limonite (of the gossan) affords quite certain information to the experienced eye of the quality of the underlying copper ore. As its porosity is indicative of the leaching away of much copper, it is likely to happen that beneath porous and open gossan will be found good ore, while, on the other hand, compactness of the limonite is an undesirable sign. . . . It is quite evident that the copper once contained in the gossan above has been leached out and redeposited.

The Fontana mine, lying not far north of the Little Tennessee River in the Great Smoky Mountain region of North Carolina, is the only active copper mine outside the Ducktown district in the eastern United States. The vein in this region has long been known but was not actively developed until 1926. The ores have proved to be of high grade, as they are reported to have averaged more than 6 percent of copper. The mine is now operating at a depth of 1,700 feet.

The numerous other veins of the region need not be described in a brief historical review of this type.

Tennessee

The greatest era of copper mining in the eastern United States began with the opening of the Ducktown district of southeastern Tennessee. The first discovery of copper at Ducktown was made on the Burra Burra lode in 1843, but no work was done until 1847, when 31,000 pounds of 25 percent ore was shipped. By 1850 active mining was in progress, and in September, 1855, 1,809,177 pounds of copper was produced. Active mining stopped during the Civil War but was resumed in 1866 and continued until about 1879, when the rich secondary ores were exhausted and the mines were closed. The advent of a railroad and improvements in the metallurgy of copper led to the reopening of the Mary mine in 1890 and the Burra Burra in 1900, and these mines have continued in operation to the present time.

Litigation over the destruction of forests by the smelter fumes compelled the abandonment of heap roasting in 1904. Plants were built for the production of sulphuric acid, which has come to be an important part of the mining industry of the region. In 1927, the latest year for which statistics are available, one of the two companies of the district produced 291,393 tons of sulphuric acid and 11,585,853 pounds of copper. In 1928 the copper production of the district was 16,374,261 pounds and the total production since the opening of the mines had been 519,017,000 pounds.

Tuomey (18), in 1858, presented a clear statement of the secondary origin of the black ores. He says:

> That portion of the vein now occupied by the gossan and ore was filled with yellow sulphuret of copper and impurities. During the changes to which the region has been subjected the yellow ore was converted into the black mass at present occupying a part of the vein. This black ore is more or less subject to spontaneous decomposition, by which it is rendered soluble, and the copper is dissolved out by every shower of rain by the simple process of leaching. In this way every atom of copper is often dissolved out from the black mass, leaving behind nothing but the impurities, silica, alumina, and oxide of iron.

Georgia and Alabama

Copper is reported from a few of the pyrite mines of Georgia, but the only mine that seems ever to have been operated primarily for copper was the Seminole, or Magruder, about 12 miles northeast of Washington, Lincoln County. This was operated as a gold mine in 1852–61 and 1880–84 and as a copper mine for a time after 1900.

Copper was discovered in Cleburne and Randolph Counties, Alabama, in 1870, and during the following decade copper was produced from the black secondary ores of the Stone Hill and Smith mines, but later attempts to mine the primary sulphides were unsuccessful.

Types of mineralization

It is not possible nor desirable to list all the copper mines and prospects of the eastern United States, but some of the more productive or interesting ones may be mentioned.

A grouping of the copper deposits of Viriginia that seems to apply very closely to nearly all those of the eastern United States has been proposed by Watson (19), as follows:

1. Pyrite bodies (worked chiefly for sulphur); type, Louisa County and Dumfries deposits.
2. Pyrrhotite bodies; Gossan Lead type.
3. Quartz fissure veins; Virgilina type.
4. Blue Ridge or Catoctin type.
5. Bodies associated with Triassic trap intrusives.

For completeness, three other groups may be added, as follows:

6. Impregnations of Paleozoic shales and sandstones; Pahaquarry type (21), of no commercial importance.
7. The copper deposits of the Maryland type (contact-metamorphic deposits in limestone).
8. Mineralized amphibolite dike.

The principal mines in these several groups are listed below.

PYRITE BODIES

Blue Hill mines, Hancock County, Maine.
Milan mine, Coos County, New Hampshire.
Davis mine, Franklin County, Massachusetts.
High Falls pyrite mines, St. Lawrence County, New York.
Chestatee pyrite mines, Dahlonega, Georgia.

PYRRHOTITE BODIES

Gardners Mountain, Grafton County, New Hampshire.
Ely or Copperfield mine, Elizabeth mine, Corinth mines, Orange County, Vermont.
Prospect Hill, western Litchfield, Connecticut.
Gossan Lead of Carroll and Grayson Counties, Virginia.
Toncray vein, Floyd County, Virginia.
Ore Knob, Alleghany County, North Carolina.
Elk Knob, Ashe County, North Carolina.
Wayhutta, Cullowhee, Savannah (Betts Creek), Black Knob, Jackson County, North Carolina.
Otto, Macon County, North Carolina.
Fontana mine, Swain County, North Carolina.
Ducktown district, Tennessee, including the Burra Burra, Isabella, Isabella-Eureka vein, Mary-Polk County, and Tennessee-Cherokee ore bodies.
Stone Hill and Smith mines, Randolph and Cleburne Counties, Alabama (pyrrhotite zones in schist).

QUARTZ FISSURE VEINS

Warren mine, New Hampshire.
Springfield, Mineral Hill, Patapsco, Sykesville, and Bare Hills, Carroll County, Maryland. (It is doubtful whether these deposits belong in this class.)
Virgilina district of Virginia and North Carolina, including the Halloway, Person Consolidated, Anaconda, High Hill, and Blue Wing mines.
Stony Point mine, Albemarle County, Virginia.
Valzinco mine, Spotsylvania County, Virginia.
Peachbottom, Alleghany County, North Carolina.
Gold Hill district, Rowan County, North Carolina.
Conrad Hill, Davidson County, North Carolina.
Copper Knob, Ashe County, North Carolina.
Trap Hill, Wilkes County, North Carolina.
Magruder or Seminole mine, Lincoln County, Georgia.

BLUE RIDGE OR CATOCTIN TYPE

South Mountain region of Pennsylvania and Maryland.
Blue Ridge region of Warren, Rappahannock, Page, Madison, and Greene Counties, Virginia, including the Sealock, Rudicall, and Manassas Gap mines and groups of prospects in the Dark Hollow, Hawksbill, Ida, Stony Man Mountain, and Hightop regions.

DEPOSITS ASSOCIATED WITH TRIASSIC TRAP ROCKS

Simsbury (Newgate) and Bristol mines, Hartford County, Connecticut.
Mount Carmel, New Haven County, Connecticut.

Schuyler mine, Arlington, Hudson County, New Jersey.
Mines near Plainfield, New Jersey.
American and other mines in Watchung Mountain region, Somerset County, New Jersey.
Flemington mines, New Jersey.
Griggstown mine, near Rocky Hill, New Jersey.
Cornwall iron mine, Lebanon County, Pennsylvania.
A group of copper prospects in southeastern Pennsylvania.
Scattered occurrences in Loudoun, Culpeper, and Orange Counties, Virginia.

DEPOSITS IN PALEOZOIC SHALES AND SANDSTONES

Pahaquarry mine, Warren County, New Jersey.
Carpenter mine, Bradford County, Pennsylvania.
Occurrences in Monroe, Pike, and Montgomery Counties, Pennsylvania.

REPLACEMENT DEPOSITS IN LIMESTONE

New London, Liberty, Dolly Hyde, and Union mines of the Frederick County belt, Maryland (associated with greenstone schists).

MINERALIZED AMPHIBOLITE DIKE

"Native copper lead" of Carroll County, Virginia.

Pyrrhotite ore bodies

Mines of the Ducktown type are the only copper mines in operation in recent years in the eastern United States, and this group will be described first.

Occurrence and structure

The ore deposits of the Ducktown type are all in the Blue Ridge or Great Smoky Mountains of the southern Appalachian region, which is characterized by strongly folded crystalline rocks. The topography throughout the region is mountainous and in places extremely rugged. Originally the entire region was covered by magnificent hardwood forests, but lumbering has left little but second-growth timber, and in the Ducktown region even this has been entirely destroyed by the fumes from heap roasting of the sulphide ores. Although the manufacture of sulphuric acid has stopped the escape of fumes, the forest has failed to reestablish itself over most of the area. The Ducktown region therefore remains a barren desert.

The ore deposits of the Ducktown type are all enclosed in schists or gneisses, which in most districts are of pre-Cambrian age, but those at Ducktown have been described as Cambrian, although they too may be pre-Cambrian. In most areas the country rock seems to have been ancient sediments, although it is not always possible to distinguish metamorphic granites from sedimentary rocks. The enclosing rocks at Cullowhee and Elk Knob are Roan gneiss, a metamorphosed ferromagnesian intrusive. The ore body at Savannah cuts a mica-bearing pegmatite of the type so widespread in the southern Appalachian region. The country rocks and most of the ore bodies strike southwest. In general the ore bodies are approximately conformable to the structure of the country rocks, as at Ducktown, although there, as elsewhere, there are numerous local departures from strict conformity.

Paragenesis

The first episode in the formation of the ore deposits of the Ducktown type was the introduction of a feldspathic rock of aplitic or pegmatitic habit. This is best shown at Ore Knob, Cullowhee, and Otto, North Carolina, and less abundantly, although quite clearly, at Ducktown and on the Gossan Lead. It seems to be absent at Wayhutta and possibly at Fontana, although abundant micas and their alteration products may here represent almost completely replaced feldspathic rock. Aplite and pegmatite are probably dikelike igneous intrusions, although locally replacement of schists has occurred. The feldspathic rock was followed by a stage in which quartz was almost the only mineral formed, chiefly in fault planes, joints, and fractures, although in many places, especially at Ducktown, on the Gossan Lead, and at Wayhutta, there was profound replacement of schist. Ferromagnesian minerals—chiefly augite, zoisite, garnet, amphiboles, gahnite (absent at Ducktown and on the Gossan Lead), biotite, chlorite, and talc—then replaced the older rocks and in a lesser degree the vein quartz. These features are clearest on the Gossan Lead, where much of the ore body has been formed by the direct replacement of schist and there are few silicates in the dolomite present; at Wayhutta and Savannah, where carbonates are absent; and at Otto and Ore Knob, where much of the vein material has replaced aplitic granite.

The ferromagnesian stage of the mineralization was followed by one in which carbonates were the only minerals formed. These are calcite at Ducktown, Cullowhee, and Otto; manganese-bearing calcite at Ore Knob; dolomite on the Gossan Lead; and ankerite that has largely replaced calcite at Fontana. The Ducktown ore bodies have been ascribed to replacement of limestone lenses in the schist (6, pp. 81–82). However, study of all the ore bodies of this type shows that the carbonates are vein materials deposited by hydrothermal solutions, like the other vein minerals. The evidence for this conclusion may be summarized as follows: Although most of the deposits generally conform in structure to the country rocks, they depart notably from strict conformity, even at Ducktown, on the Gossan Lead, and at Otto. At Ore Knob the vein is nearly vertical and transects the structure of the country rock, which dips about 45°. Nevertheless, the Ore Knob vein carries as much calcite as those at Ducktown or in parts of the Gossan Lead. The Savannah vein appears to strike almost normal to the country rocks, but here carbonates are practically absent.

Although carbonates are associated with many veins, others have formed in the absence of carbonate (Savannah, Wayhutta, and parts of the Gossan Lead). At one well-exposed deposit on the Gossan Lead even the richest lenses of ore represent direct replacement of schist. At Savannah the vein has been formed partly by replacement of schist and partly by replacement of a mica-bearing pegmatite. The country rock at Elk Knob and Cullowhee is Roan gneiss, a highly metamorphosed ferromagnesian intrusive. At Cullowhee numerous lenses of very pure calcite occur, although the enclosing rock is igneous, and limestone lenses are precluded.

At Ore Knob many calcite veins cut aplite. At Cullowhee much of the feldspar has been partly replaced by calcite. In the northernmost workings of the Landon mine, at Ducktown, the vein is not over 3 feet wide and consists essentially of quartz. Calcite and sparse sulphides are confined to shear zones in the quartz. Microscopic examination shows that quartz and most of the ferromagnesian minerals have been partly replaced by calcite. After the calcite was deposited it was partly replaced by lime silicates. The intensity of this stage varied greatly from mine to mine. In the Ducktown district is was probably more extensive than elsewhere. In parts of the Gossan Lead and at Ore Knob the purer calcite masses contain abundant sulphides but only small amounts of lime silicates. The deposition of sulphides ended mineralization in most of the deposits. The sequence of sulphides was in general pyrite, pyrrhotite, sphalerite, chalcopyrite, and lastly a little galena. A wide gap occurred between pyrite and the other sulphides, but these later ones overlapped somewhat in periods of formation.

The deepest mine in the Ducktown district is the Burra Burra, which has reached a depth of 1,800 feet, and the vein has been very uniform in character to that depth. Perhaps the deep ores are slightly more siliceous, and at the same time chalcopyrite has increased in relation to the other sulphides, but this change is very slight at most. As the veins are approximately conformable, the character of the country rock does not change with depth. This indicates that except where cut off by faulting the ores may be expected to continue to at least the depth of profitable mining without marked changes in character.

Age

The age of the deposits of the Ducktown type in the southern Appalachian region is not directly determinable. They cut pre-Cambrian and perhaps Cambrian rocks, but no younger rocks are found in the immediate region. The veins show no effect of postmineral metamorphism, and drusy cavities have not been destroyed by postmineral orogenic movements. This indicates that they are later than the last major period of mountain building, which was in late Carboniferous time. The Savannah vein cuts a typical mica-bearing pegmatite, and other pegmatites of the region have been determined to be of Permian age by the lead-uranium ratio of pitchblende. This confirms the structural relations in indicating formation near the end of the Paleozoic era.

Future of the Ducktown district

The ore reserves in the Ducktown district are sufficient for many years' requirements. The copper content of the ores treated has been gradually decreasing, but the production of sulphuric acid has long been a major asset, the ore-carry a zinc content (which is being recovered by flotation) nearly equal to the copper, and the sinter, which can be reduced to a low zinc-sulphur content, is being increasingly used as an iron ore. Thus, under normal conditions, a high-sulphur ore running less than 1 percent of copper can be successfully treated.

The Burra Burra ore body has a width of 35 to 75 feet, a length of over 3,000 feet, and drifts on the different levels 1,000 to 3,000 feet in length. The vein dips about 72° SE. and has been followed down the dip for 1,800 feet. At that depth the ores appear to be slightly more siliceous than at higher levels, but the proportion of chalcopyrite to other sulphides has increased, so that the tenor of the ores is maintained. The regularity of the vein in depth is so great that it may be expected to persist without marked change to the depth of profitable mining.

The Isabella-Eureka ore body, which is 1,500 feet long and 100 to 250 feet wide, is probably the largest in the district. The ores run less than 1 percent of copper but are high in sulphur and are profitably worked when the price for sulphuric acid is normal.

The Old Tennessee (School Property) Cherokee mines extend for nearly a mile. The ores are reported to be similar to those of the Isabella-Eureka and contain large masses of pyrite.

The Mary has been one of the two great mines of the district, but the bottom of the ore body appears to have been reached, and the mine is not now being operated.

Other ore bodies are known, but their character has not been systematically investigated.

The ores now blocked out in the Ducktown district amount to many millions of tons, and those which may be reasonably expected to become available no doubt amount to many millions more.

Catoctin ores

The copper ores of the Catoctin type of the Blue Ridge region of Virginia and the South Mountain region of Maryland and Pennsylvania have been most fully described by Watson (20), from whose report the following description is summarized.

The Catoctin belt persists as a fairly well defined unit from middle northern Virginia through Maryland into Pennsylvania. Similar occurrences in smaller areas are found in the Piedmont province of Virginia and North Carolina. The deposits are strikingly similar in occurrence, structure, and mineralogy.

Keith recognized two flows of basic lava, separated by an erosion interval of considerable length during which flows of andesite and rhyolite and intrusions of granite began. The basic lavas represent accumulations of unknown but probably great thickness from subaerial fissure eruptions. The flows commonly have amygdaloidal tops.

Regional and chemical metamorphism of the basic lavas has been pronounced and widespread, as shown by their strongly developed schistose structure and the extensive development of epidote, chlorite, and, in places, quartz and some asbestiform serpentine. The ores are found chiefly in such altered portions of the rock, and the copper occurs in places in intimate association with each of these minerals, but most commonly with epidote, hence it seems probable that the epidote is genetically connected with the copper.

Native copper is the chief ore mineral and is commonly associated with cuprite, some bornite and chalcopyrite, and locally a little chalcocite. The bornite is probably in excess of the chalcopyrite. Malachite and azurite are nearly constant oxidation products as stains in the surface rock and as films and coatings on joint and fracture surfaces. Chrysocolla is of sparing occurrence. Cuprite is also secondary after the native metal, which in places forms nucleal masses surrounded by the oxide. Masses of the native metal weighing several pounds have been reported but are exceptional.

Watson thought that the source of the copper in the Appalachian region was in the pre-Cambrian basic lavas, where it probably originally existed in the form of sulphide and was concentrated as native metal in its present position by hot circulating waters coextensive with the epidotization and the formation of quartz veinlets, under the oxidizing influence of ferric iron in the epidote. More specifically the native copper was probably derived from sulphide solutions entering the rocks rich in ferric iron as epidote along zones of shearing and sheeting. The ferric iron oxidized the sulphur of the solutions, and the copper was deposited as native metal. Watson thought that the principal period of mineralization was pre-Cambrian, and this view is in close accord with that of several other geologists (17).

Weed (21) and Phalen (12), on the other hand, concluded that the copper was concentrated from the greenstones by downward-percolating waters. Weed thought that the copper came from the mass of the basalt, where it probably existed as disseminated chalcopyrite and perhaps as cupriferous pyrite. These minerals have been dissolved by percolating waters, carried away, and redeposited with vein minerals along joint planes of the rock.

The distribution of the ores, their relations to the porous, originally oxidized basalt flows, and the associated minerals indicate that they were deposited by hot ascending solutions, as suggested by Watson. However, the derivation of the copper directly from the enclosing basalts does not seem equally clear. Evidence seems to be lacking to determine whether the copper was supplied by some deep-seated igneous rock or came directly from the basalt.

Quartz veins

The Virgilina district of Virginia and North Carolina is the best example of the quartz-vein type of copper deposit in the eastern United States and has been carefully studied by Laney (8), from whose description the account here given is largely taken.

The Virgilina district lies in the Piedmont region about 40 miles east of Danville, Virginia. The country rocks of the veins are highly metamorphosed, originally andesitic volcanic rocks. The veins were not formed until the volcanic rocks had been folded and metamorphosed into greenstone. The essential gangue minerals of the veins, named in the order of their abundance, are quartz, calcite, epidote, chlorite, hematite, sericite, and albite. The ore minerals, named in the order of abundance, are bornite, chalcocite, native copper, malachite, azurite, cuprite, chalcopyrite, chrysocolla, pyrite, argentite, silver, and gold.

The veins occur in fractures, possibly faults, which intersect the schistosity of the greenstones at acute angles and which, therefore, were not formed until after the rock had become a schist. Hence the source of the vein matter must be sought entirely outside of the rock in which they occur, the Virgilina greenstone of Laney. The source must have been a rock or magma that could normally supply the highly siliceous gangue minerals, quartz and orthoclase, as well as the ore minerals, and at the same time provide for the formation of the other gangue minerals, such as epidote, chlorite, calcite, and plagioclase. The only rock in the district—or in the region, for that matter—which fulfills all these conditions is the granite. Laney therefore believed that the veins were genetically related to the granitic magma, that the sulphides, the orthoclase, the greater part of the quartz, and possibly the plagioclase were derived directly from the granitic source, and that the other minerals were derived largely from the country rock through alteration of its normal minerals. The deposition was believed to be due to such factors as decrease in temperature and pressure of the rising solutions, their commingling with other solutions, and the influence of the wall rock of the fissures through which they were moving.

An interesting vein, apparently of the same type, occurs near Stony Point, about 8 miles northeast of Charlottesville, Virginia. Here a gossan over a strong vein was mined for iron ore about 1885. At a depth of about 130 feet partly oxidized chalcopyrite began to appear. The mine was abandoned before entirely fresh primary ores were encountered, but large masses of chalcopyrite can still be found on the dumps. It is evident that the chalcopyrite was the only essential sulphide, and the gangue minerals were largely ankerite and quartz. The derivation of a minable iron ore from a vein of this type suggests a promising copper vein.

Maryland deposits

No adequate study that was made while the copper mines of Maryland were in active operation is available, and this is more regrettable inasmuch as some of these mines were of real commercial importance before the western mines became productive. However, Overbeck (11), from whose work the following description is taken, has carefully studied the ores and effectively summarized all the available information.

Copper mining in Maryland began before 1760 and has continued to the present time. The production, though small, was of considerable importance prior to the middle of the nineteenth century, but it is now insignificant.

All the commercially utilized deposits occur in the metamorphosed complex of the Piedmont, where the country rocks include metamorphosed sediments and early eruptives with later less metamorphosed eruptives. In the east, associated with the deposits of Baltimore County and eastern Carroll County, deep-seated igneous masses predominate; in the west, associated with the deposits of Frederick County, metamorphosed acidic and basic lavas and tuffs are abundant.

The deposits in eastern Carroll County, comprising those at Finksburg, Mineral Hill, and Springfield, lie along a definite line of structural weakness that is traceable for many miles across the State. The country rock of the region consists of phyllite and quartz-mica schist. A large granite intrusive lies near the south end of the copper belt, and pegmatite dikes are common throughout the region. Altered basic intrusives are present along the line of weakness, and the copper ores are associated with these rocks. The ore occurs in replacement veins roughly conformable in attitude with the country rock. The metallic minerals are chalcopyrite, bornite, carrollite, chalcocite, covellite, sphalerite, magnetite, and specularite. Chalcopyrite, bornite, sphalerite, magnetite, and specularite form primary intergrowths; chalcocite and covellite are everywhere secondary, replacing all the earlier minerals except magnetite and specularite. The gangue minerals are hornblende, biotite, epidote, and feldspar, all of which are partly replaced by the ore minerals. The paragenesis is magnetite, hornblende, biotite, epidote, quartz, feldspar, magnetite, carrollite, sphalerite, chalcopyrite and bornite, secondary chalcopyrite, covellite, chalcocite.

The mineralogy of the deposits indicates their deposition from hot ascending solutions at considerable depth. Supergene alteration to chalcocite has taken place along crevices in the ore but is of slight extent. Deposition occurred after the metamorphism of the region, probably in post-Ordovician time. The source of the ore-bearing solutions was probably the granitic magma from which the pegmatitic material came, as suggested by the proximity of a large granitic mass and by the general agreement in age of the ore deposition and the granitic intrusion.

The deposits of Frederick County, at Liberty and New London, are confined to limestones at or near their contact with other rocks. The country rock of the region consists of metamorphosed sedimentary rocks and altered acidic and basic extrusives. The ores occur as pockets and stringers in limestone or as deposits formed by the replacement of calcareous bands in impure limestone. The ore minerals are chalcopyrite, bornite, and chalcocite. Quartz, calcite, and barite form the gangue minerals. Chalcopyrite and bornite are primary; bornite and chalcocite occur in graphic intergrowths and are in part probably contemporaneous in origin. Supergene chalcocite is prevalent but not abundant. The paragenesis was calcite (?), barite (?), quartz, chalcocite, chalcopyrite, bornite, secondary chalcopyrite, secondary chalcocite. Some quartz is probably contemporaneous with the ore minerals.

The mineralogy suggests deposition from hot ascending waters at moderate depth. Mineralization apparently took place after the regional metamorphism. The source of the ore-bearing solutions is not certain, but as the mineralization was probably contemporaneous with that in Carroll County, the ore-bearing solutions probably had a common source. There is no evidence that the solutions were derived from the greenstones of the region, with which many of the deposits are associated.

Copper deposits associated with Triassic traps

Many of the copper deposits associated with the Triassic intrusives were briefly exploited and abandoned before the days of detailed geologic descriptions, but deposits of this type have been described by Lewis (9), Wherry (22), and Bateman (1). As these authors agree on the general geologic relations, the following discussion is based on their papers, particularly that of Lewis.

The most characteristic sedimentary rocks of the Triassic of New Jersey are fine-grained red shales, but thick-bedded sandstones also occur, chiefly in the lower parts of the section, and coarse conglomerates appear at the base and at other horizons. Traps of both extrusive and intrusive varieties occur; lavas form broad, thick sheets, chiefly in the Watchung Mountains; and intrusive sills and dikes appear prominently in the Palisades and in various smaller masses in southwestern New Jersey.

Chalcopyrite is visible at many places in the traps, both in the fresh rock and in the veins of secondary minerals resulting from their alteration. Native copper also occurs in the trap in the quarries at Chimney Rock (near Bound Brook) and near its contact with the underlying shales in the American mine, north of Somerville. Stains of chrysocolla and malachite are common in joints near weathered outcrops.

The fresh traps also carry copper as a constituent of the pyroxenes. Numerous assays of the lava of First Mountain yielded an average of 0.025 percent of copper, and the pyroxenes from the intrusive trap of Rocky Hill carry 0.019 percent.

All mining and prospecting have been confined to the sedimentary rocks, where the shales and sandstones locally carry disseminated grains and irregular masses of copper ores, with a few veinlike aggregates and impregnated fault breccias.

The copper occurs chiefly as chalcocite and native copper. Chrysocolla and smaller quantities of cuprite, malachite, and azurite are commonly associated. Lewis recognized four distinct types of ore association, two with and two without accompanying intrusive trap, as follows:

With intrusive trap rocks: (1) In baked sediments accompanying the trap, as in the Rocky Hill (Griggstown) mine; (2) in unaltered sediments intersected by dikes, as in the Arlington (Schuyler) and Flemington mines.

Without associated intrusives: (3) In unaltered or very slightly altered sediments with lavas, as at numerous localities along First Mountain near Pluckamin, Somerville, Bound Brook, and Plainfield; (4) in unaltered strata entirely apart from known trap masses of any kind.

The copper mine at Bristol, Connecticut, occurs on the faulted contact between ancient schists and red arkosic Triassic sandstones. This mine is famous for its superb crystals of primary chalcocite. The ores occurred as veins in schist, as disseminated ore in schist, and as disseminated ore in Triassic sandstone. Bateman (1) believes that in Triassic time, while the red arkosic sandstones were being deposited, the magmatic reservoirs that furnished the trap intrusives and extrusives also emitted mineralizing solutions. Part of these solutions were guided in their upward course by the channelway of the Bristol fault, and by the time they reached the site of the present ore deposit they had a temperature somewhat less than 91° C. Their temperature and chemical composition prevented them from altering the wall rocks appreciably, but they removed ferric oxide from the red sandstones.

In discussing the origin of the ores at the Cornwall mine, Pennsylvania, which are in large part magnetite but which also contain copper, Spencer (16) says:

> If the various deposits be considered together, the theory of origin which seems to be required by their geologic relations is that the magnetite ore bodies of the Cornwall type have been formed by the more or less complete metasomatic replacement of sedimentary rocks by iron minerals precipitated from heated solutions set into circulation by the invading diabase. The rocks which have been thus replaced are usually limestones, limy shales, or limestone conglomerates. . . .
>
> All things considered, if it be admitted that the heat of the intrusive rocks was the prime cause of the circulation of the solutions which formed the ore, it appears more likely that both the waters and the iron were furnished by the igneous rock than that they could have been derived from an outside source.

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The copper deposits of Arizona[1]

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General history

The oxidized copper ores of Arizona attracted attention almost as soon as the territory was acquired from Mexico, in 1848 and 1853. The first to be exploited were the relatively more accessible deposits of Ajo (1854) and those near the junction of the Colorado and Williams Rivers (about 1860). Arizona copper ore commanded a premium because of its freedom from arsenic and antimony and the ease of reduction of the thoroughly oxidized sulphur-free ore. However, the wild frontier conditions then existing were stupendous handicaps, and production was negligible.

The first real copper mining was done at Morenci in 1873, when the Lezinskys, merchants of Silver City, New Mexico, acquired the rich oxidized outcrops of the Longfellow mine. The nearest railroad point was then La Junta, Colorado, 700

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miles northeast, and goods for the Lezinsky store were hauled over the more accessible road from St. Louis to Santa Fe, New Mexico, and thence down the Rio Grande to Silver City, a total distance of 1,200 miles. Little or no produce was hauled out, but as copper was then commanding a high price, the Lezinskys conceived the plan of smelting the rich Longfellow ore at the mine, using locally burnt charcoal as fuel, and hauling the black copper to St. Louis on the otherwise empty return trips of their trains. The venture thrived and expanded from a daily capacity of 2 tons of ore to 40 tons in the 10 years before the completion of the transcontinental railroads. During this time 25,000,000 pounds of copper was produced, a truly remarkable achievement.

The first transcontinental railroad was the Union Pacific, completed in 1869. The two southern lines across Arizona were not completed until the early eighties. They introduced an entirely new era in mining, and the modern industry in the State dates from that time. Under the stimulus of high prices for copper the whole territory was rapidly prospected during the slow building of the railroads in the late seventies. Every important deposit in Arizona had been found and begun to be exploited by the time the two railroads were completed. Most of these early ventures were financed by relatively weak companies, which were unable to withstand the price decline of 1884 and 1885, when copper dropped to 8¾ cents a pound. The largest and best deposits were acquired by three strong companies, headed by three unusually able men. The deposits of Bisbee and Globe passed under the domination of Phelps, Dodge & Co., headed by Dr. James Douglas, commonly called the "father of copper mining in Arizona." The Longfellow mine, at Morenci, passed to a strong Scotch company, the Arizona Copper Co., dominated by James Colquhoun. Phelps, Dodge & Co. also acquired valuable interests in the camp. The United Verde deposit, at Jerome, was acquired by William A. Clark, of Montana.

Copper prices remained low after 1885 for over 12 years, owing to conditions very similar to those faced at the present time. A potential world oversupply existed because of too rapid exploitation of the deposits of Butte (Montana), Calumet (Michigan), and Arizona. The price level during this period remained uniformly low, and it was only by careful cooperation of the leading operators in controlling production that chaotic conditions were avoided.

The four large Arizona copper camps mentioned gradually expanded operations until about 1900, when the rapidly increasing demands of the electrical industry were reflected in higher price levels. In the succeeding 15 years the smaller deposits of Silver Bell, Helvetia, Swansea, Superior, Courtland, Patagonia, Christmas, and several in Yavapai County, whose exploitation had begun in the early eighties, were revived, and some of them were largely exhausted. Large newly discovered deposits of low-grade ore were exploited and soon dominated production. Miami, Inspiration, Ray, and Ajo were the principal deposits of this type. Most of these new ventures were financed by new companies, so that centralized control of the industry no longer existed, and distress was imminent in 1914, on the outbreak of the World War. The unprecedented demand during the war and the decade following resulted in feverish expansion and fluctuating prices.

The collapse of all commodity prices in 1930 affected Arizona copper mining disastrously. By the end of 1932 only three mines in the State were producing, and these on a much curtailed basis.

Production

Arizona has produced a very substantial proportion of the total copper mined in the world. If the world's known major copper districts are classified according to their total production or potential production into class A districts (those which have produced or will produce $1,000,000,000), class B districts ($500,000,000 to $1,000,000,000), and class C districts ($100,000,000 to $500,000,000), there are 15 class A districts in the world, of which 4 are in Arizona. Of class B districts, Arizona has 1, and of class C, 2.

The total production of the State since its acquisition from Mexico in 1848 and 1853 to the end of 1929 has been about 6,271,471 metric tons of copper, which was sold for about $2,000,000,000. The whole world production from 1801 to the end of 1929 has been about 39,542,438 metric tons. Arizona has thus produced nearly 16 percent of the total copper mined in the world in this period.

Geomorphology

The southern Rocky Mountain region, of which Arizona covers a part, may be separated into four broad topographic provinces (1), with a fifth minor province in Colorado and northern New Mexico. The largest of these provinces, around which the others are clustered, is the Colorado Plateau province (see pl. 6), which covers a roughly circular area of about 160,000 square miles. It is separated from the Great Plains province of the central United States by the Rocky Mountains of Colorado and northern New Mexico. The Colorado Plateaus are characterized by nearly flat-lying Paleozoic and Mesozoic sediments resting on a pre-Cambrian complex of schist, gneiss, and Proterozoic sediments. The area is a high plateau through which the present streams have cut deep canyons, of which the greatest is the Grand Canyon of the Colorado. The region has been intruded by isolated small laccolithic masses of intermediate to basic composition. Large normal faults on the west separate the plateau from the Basin Range province of western Utah and Nevada. To the south, in northwestern New Mexico, the plateau grades insensibly into the Mexican Highland province. In Arizona the separation of the two provinces is sharply defined, where exposed, by normal faults, but much of the boundary is masked by extensive fields of generally basic lava, with main extrusive centers in the White Mountains and San Francisco Peaks and southwest of the Juniper Mountains. The Mexican Highland province in Arizona forms a belt of high northwestward-trending mountain ridges separated from one another by detritus-filled intermontane troughs of about the same width as the ridges. This mountain area, about 100 miles wide, borders the Colorado Plateaus from the southeast corner of the State nearly to the northwest corner, where it joins the Basin and Range province. At its southeast end its width increases to 150 miles and the ridges near its western boundary trend north. The southwestern third of Arizona forms a part of the Sonoran Desert region, characterized by low, maturely eroded ridges (2, pp. 150–153) striking predominantly northwest, separated by flat detritus-filled plains several times the width of the ridges. The boundary of the mountain area is generally sharp. The principal difference between the two areas is due to the relative uplift of the mountain area as a whole with respect to the desert region, after the greater part of the detritus of the intermontane troughs had been deposited. The ridges in the mountain area are now being vigorously eroded, whereas the desert ridges are approaching maturity. The detritus of the intermontane plains in the mountain area is generally being heavily trenched, whereas in the desert region aggradation continues or is keeping pace with degradation. These statements are generalizations only, and numerous exceptions exist.

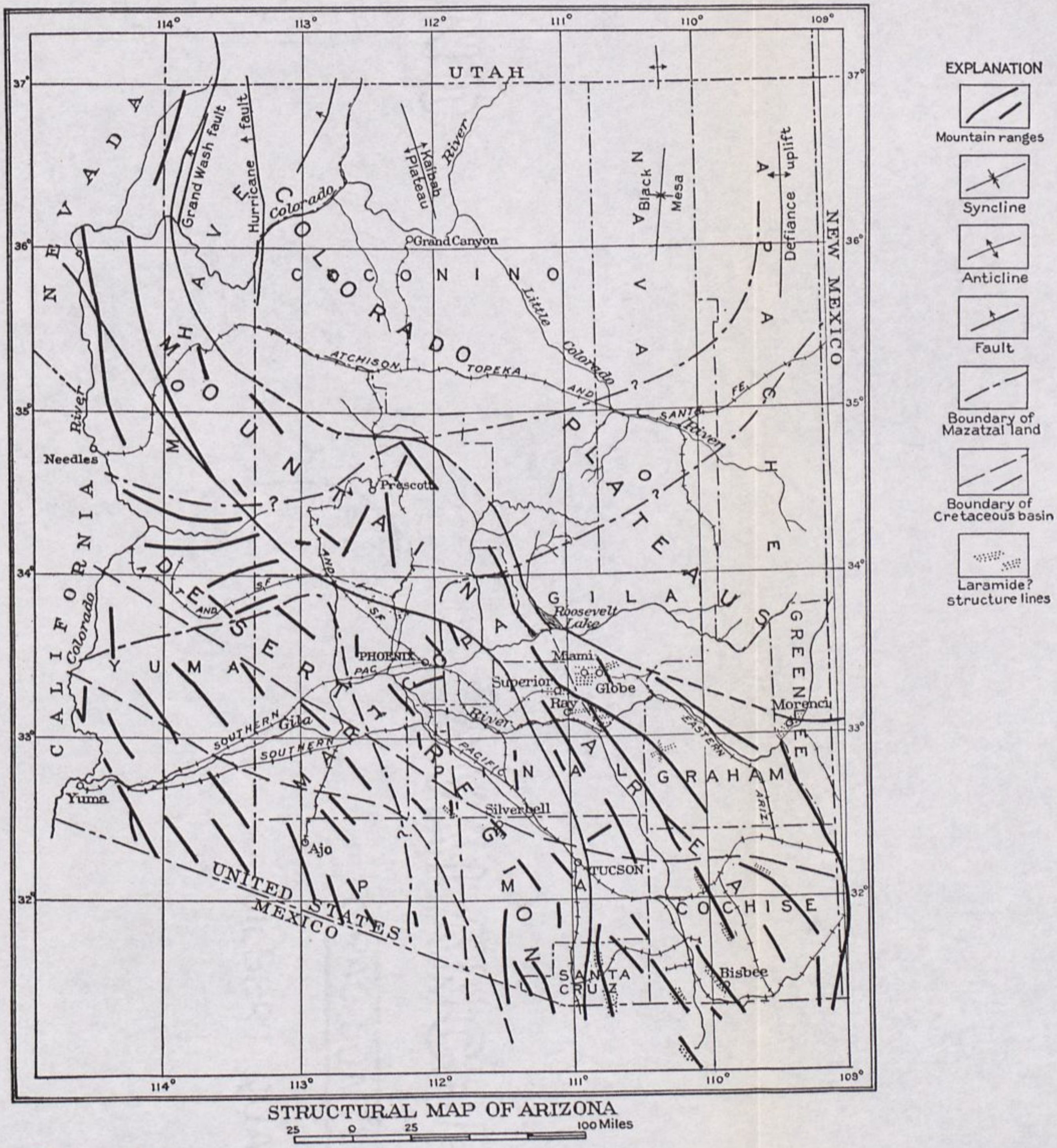
Geology

Stratigraphy

The pre-Cambrian basement rock, exposed in the bottom of the Grand Canyon, in the Colorado Plateaus, and in many of the ranges of both the mountain area and desert region, is schist of variable composition derived chiefly from sandstones and shales and partly from igneous rocks. This old formation is known as the "Vishnu" in the Grand Canyon, the "Yavapai" in the Bradshaw Mountain area, and the "Pinal" in central and southeastern Arizona. The schistosity is almost invariably parallel with the original bedding of the sediments. The strike is prevailingly northeast but varies between N. 20° W. and N. 60° E. Dips are generally steep. The schistosity was completely developed before the deposition of the earliest known Proterozoic sediments, the basal conglomerates of which contain schist boulders. The schist has consequently been called "Archean." This old formation was intruded by an enormous granitic batholith, one of the largest exposed in the world. Probably most of the schistosity was developed immediately before and coincident with the intrusion of the magma. After the intrusion the whole area was probably reduced to low relief.

In the center of the State several isolated remnants of highly indurated quartzites, conglomerates, and slates (Mazatzal), to a maximum thickness of 2,400 feet (3, pp. 299–312), rest on schist and granite and probably record an old sedimentary basin. Similar quartzite occurs in the northeast corner of the State, at the crest of the Defiance uplift within the Colorado Plateaus. The width of the area of exposure from Del Rio to the north end of the Mazatzal Mountains is 80 miles. In this area the truncation of the pre-Cambrian batholith before the deposition of the Mazatzal ranged from deep apical to medial. In a belt of pre-Cambrian schist and granite exposures of about the same width trending west-southwest across the State as far as the Colorado River at Parker, with a possible southern arm extending from the Bradshaw Mountains to the Mexican border, the batholith has been truncated to about the same degree. Possibly this belt represents the basin of deposition of the Mazatzal quartzite, and deeper truncation of the batholith was prevented by protection of the quartzite covering, since removed by erosion. The pre-Cambrian batholith on all sides of this belt has been far more profoundly truncated.

Good evidence, presented below, shows that before the late Proterozoic and Cambrian sediments in the Cordilleran Paleozoic geosyncline were deposited, a pre-Cambrian land mass was elevated into a mountain highland probably



STRUCTURAL MAP OF ARIZONA

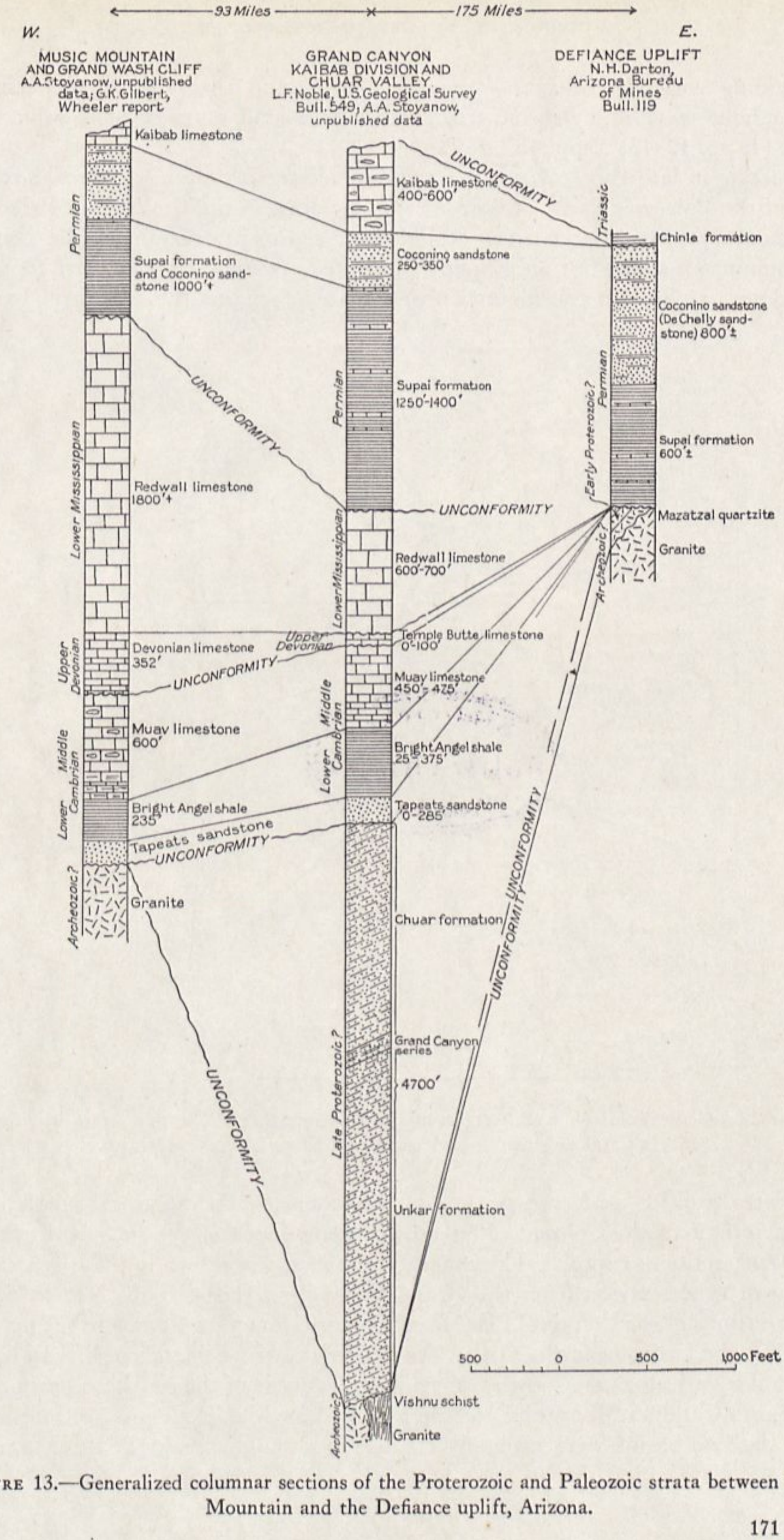


FIGURE 13.—Generalized columnar sections of the Proterozoic and Paleozoic strata between Music Mountain and the Defiance uplift, Arizona.

coinciding with the Mazatzal quartzite basin, and that this ridge persisted throughout most of Paleozoic time, either as a land mass or as a submarine ridge (4, pp. 12–13; 5, pp. 157–159).

Starting in late Proterozoic time and extending with numerous breaks to the end of the Paleozoic, most of Arizona was included in the Cordilleran Paleozoic sedimentary basin. Large areas of Paleozoic sediments remain in the plateau and mountain areas, but only highly indurated erosional remnants are found in the desert region. In the mountain and plateau regions the Mazatzal barrier

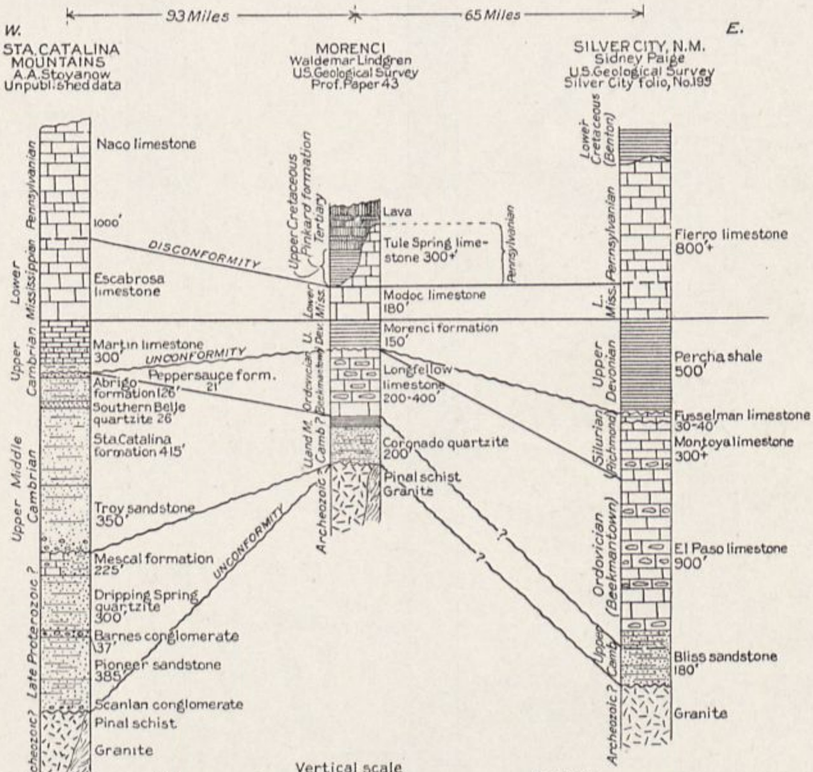
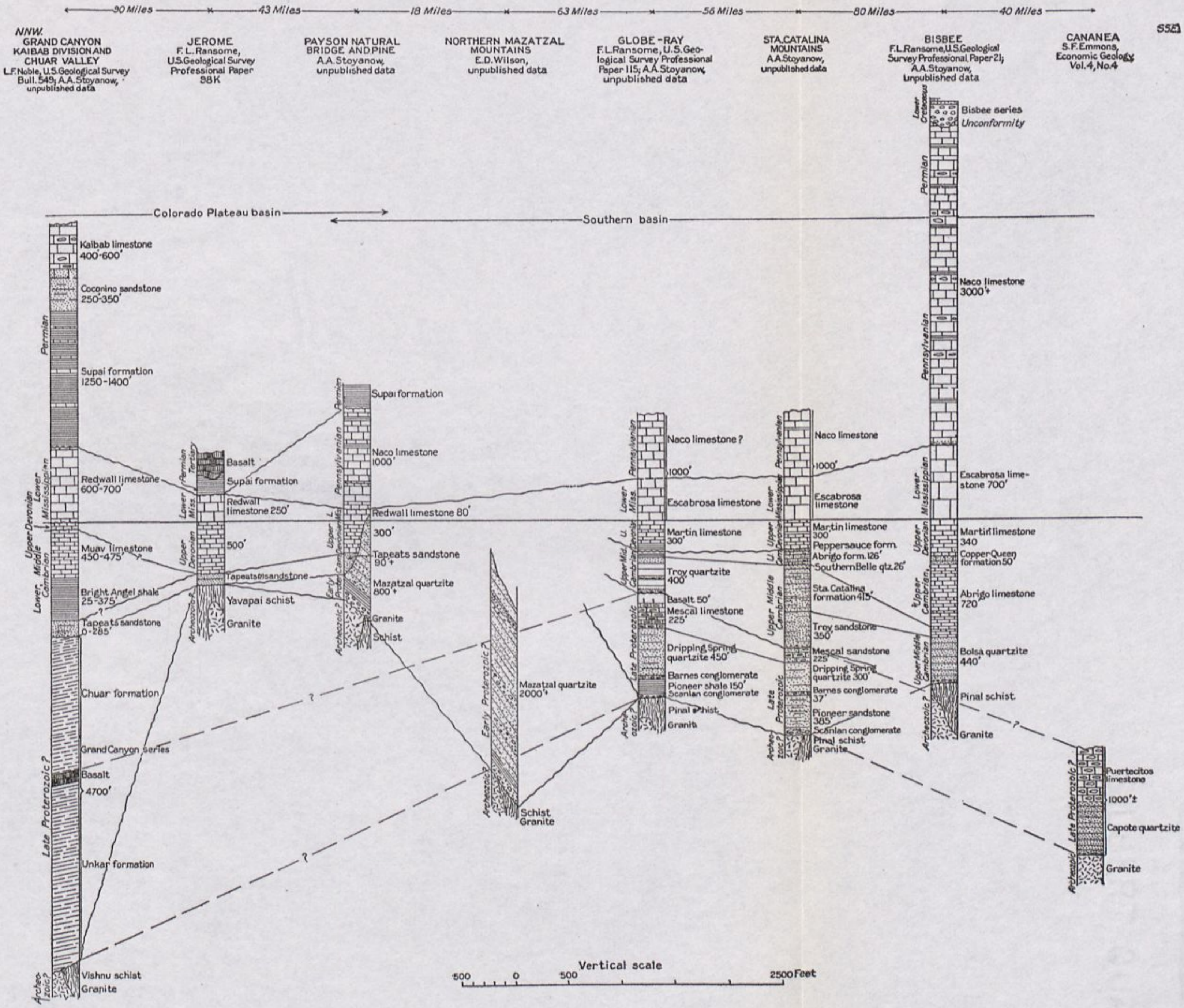


FIGURE 14.—Generalized columnar sections of the Proterozoic and Paleozoic strata between the Santa Catalina Mountains, Arizona, and Silver City, New Mexico.

separates two different type sections of the Paleozoic, the one to the north being characteristic of the Colorado Plateaus, whereas south of the ridge a distinctly different section is exposed. The general differences are shown in plate 7, a correlation of type sections from the Grand Canyon southeast to Bisbee. In figure 13 variations in the Colorado Plateau section are shown transverse to the general trend of the basin, from the Grand Wash Cliffs to the Defiance uplift. In figure 14 similar variations are shown transverse to the axis of the southern basin from the Santa Catalina Mountains to Silver City, New Mexico. These sections show that the two basins were probably connected through breaks in the Mazatzal



GENERALIZED STRATIGRAPHIC SECTIONS OF THE PALEOZOIC AND PROTEROZOIC STRATA BETWEEN GRAND CANYON, ARIZONA, AND CANANEA, MEXICO

ridge during late Proterozoic time (6, pp. 26–27) and again during Mississippian (Madison) time. In both basins there are unconformities between the Proterozoic and Cambrian and between Cambrian or early Ordovician and late Devonian, with less profound disconformities between Mississippian and Pennsylvanian and between Pennsylvanian and Permian. The greatest contrast in sedimentation between the two basins was during late Carboniferous time, when extensive marine limestones were deposited in the southern basin, whereas in the Colorado Plateau basin, in Arizona, littoral and terrestrial red beds and gypsiferous limestones represented by the Supai, Hermit, Coconino, and Kaibab formations were deposited. In both basins the thinning and extinction of the earliest sediments shows encroachment on a land mass toward the east. This is more pronounced in the Colorado Plateaus, where all pre-Permian sediments wedge out between the Grand Canyon and the Defiance uplift. In the southern basin only the Proterozoic and Cambrian sediments are involved. In both basins a great unconformity—more profound, however, in the southern basin than in the Colorado Plateaus—exists between the Paleozoic and Mesozoic.

During the Mesozoic era two basins of deposition existed in Arizona. In the northern basin, limited during early Mesozoic time to the present Colorado Plateaus, Triassic littoral mud, marl, and conglomerate were deposited disconformably over a level surface of Permian limestone and sandstone, followed by Jurassic (dune?) deposits of highly cross-bedded white and brown sandstone. In Upper Cretaceous time a series of sandstones and shales with extensive coal measures was deposited. During the late Mesozoic the basin encroached southward on the present mountain area as far as Morenci and the Deer Creek coal field, east of Hayden, and possibly as far as the Tucson Mountains, where Upper Cretaceous formations with flora and fauna suggestive of Colorado affiliations are found (7). A composite section in the Colorado Plateaus includes 1,630 feet of Triassic strata, 900 feet of Jurassic, 600 feet of Lower Cretaceous (?), and 800 feet of Upper Cretaceous—a grand total of 3,930 feet (8, pp. 24–76). In the Deer Creek coal measures about 1,000 feet of sandstone, shale, and coal are interbedded with andesitic tuff and agglomerate unconformably overlying Carboniferous limestone (9, pp. 240–258). In the Tucson Mountains at least several hundred feet of Upper Cretaceous shale and limestone have been observed (10). At Morenci 200 feet of Upper Cretaceous unconformably overlies Paleozoic sediments (11, p. 105).

A second basin of deposition, which transgressed parts of the present mountain and desert regions from the southeast was begun in late Lower Cretaceous time, when it spread northward at least as far as the Dos Cabezas Mountains and possibly as far as the Tucson and Santa Catalina Mountains. In the desert region unfossiliferous post-Paleozoic shale and conglomerate are found as far northwest as the Vekol Mountains (75 miles northwest of Tucson); and Mesozoic sandstone, shale, conglomerate, and impure limestone in Yuma County, in the Castle Dome, S. H., Middle, Tank, and New Water Mountains (about 120 miles farther northwest), may have been deposited in this same Cretaceous basin (12). The earliest of these sediments were deposited in the southeast corner of the State, typically represented by the section at Bisbee, where 4,500 feet of conglomerate, sandstone, shale, and limestone has been measured (13, pp. 60–61). Very great thicknesses, locally well over 10,000 feet, of partly terrestrial sediments in the Tombstone, Whetstone, Empire, Santa Rita, and Patagonia Mountains are at least in part early Upper Cretaceous (14). In the central part of the mountain area the difference in attitude of the Cretaceous and Paleozoic sediments is slight, although extensive pre-Cretaceous trenching is shown, as at Bisbee (13, p. 60). On the western border of the mountain area and in the desert region, marked differences of attitude exist (15, pp. 269–277). Evidently at the dawn of the Mesozoic the mountain area and desert region of Arizona were elevated as a whole with respect to the Colorado Plateaus, which remained during all of Mesozoic time a low area close to sea level. This low area had by Cretaceous time been extended over the greater part of the mountain area by encroachments from the north and from the southeast. The southeast encroachment from northern Mexico possibly extended as a northwest arm across the desert region at least as far as Quartzsite, in northern Yuma County, a total distance in Arizona of 340 miles.

Igneous activity

Extensive intrusion and extrusion by magmas of basic to acidic composition have occurred in both the mountain area and the desert region. The largest intrusive that crops out is the enormous pre-Cambrian granitic batholith comprising most of the exposed pre-Cambrian of the mountain area and desert region. This mass extends southward into Mexico, westward into California, and northwestward into Nevada. Its exposed area in Arizona, including schist roof pendants, is 9,000 square miles. It is deeply truncated in the desert region, where roof pendants are small, but in the mountain area the truncation has generally reached the deep medial stage, and larger exposures of schist are found. No post-Cambrian batholiths comparable in size to the Sierra Nevada batholith of California and the Boulder and Idaho batholiths of the northwestern United States have been exposed anywhere in Arizona. Numerous small intrusives, generally post-Cretaceous, are scattered over the whole of the mountain area and desert region. No one mass exceeds 300 square miles in area, and the average is not over 25 square miles. The depth of truncation also varies, but in general in the mountain area apical truncation prevails, whereas in the desert region and in the bordering part of the mountain area truncation is medial or basal. Diabase occurs extensively as sills in Proterozoic sediments in central Arizona and also in the lower members of the Proterozoic series of the Grand Canyon.

Large volcanic fields of lava, agglomerate, tuff, and breccia are found in both the mountain area and the desert region, the largest, already noted, on the border of the Colorado Plateaus. These border fields extend from 10 to 30 miles into the mountain area, as at Morenci and the Natanes Plateau, 50 miles to the northwest, and on the headwaters of the Verde River, southeast of Camp Verde. Other extensive fields are found well within the mountain area and desert region. The largest field is in the desert region in central Yuma County, western Pima County, and southwestern Maricopa County and covers an area 150 miles long by 50 miles wide. In the mountain area the largest field is that in western Mohave

County, in the Black Mountains, along the Colorado River, extending southeastward from the Boulder Dam for 145 miles, with an average width of 15 miles. A second large field (73 miles long by 15 miles wide) is in the Galiuro Mountains, in south-central Arizona. The Chiricahua Mountain field, in the southeast corner of the State, extends southward into Mexico and eastward into New Mexico; its area of outcrop in Arizona is 50 by 25 miles. A fourth field, much dissected by erosion, is in central Yavapai County, south of Prescott, and covers a total area, including exposed basement, of about 2,500 square miles. A fifth field, of about 600 square miles, is that of the Superstition Mountains and the adjoining dacite plateau, between Superior and Globe. A sixth extensive field, much trenched by erosion, covers most of Santa Cruz County and extends southward into Mexico. The total area in Arizona, including exposed basement, is about 1,575 square miles. Besides these six major fields, scattered small fields are numerous.

The older extrusives are generally intermediate to acidic; the youngest, probably Quaternary, are predominantly basaltic. The age of the extrusions is uncertain, owing to the absence of fossils in sediments younger than Upper Cretaceous, except in western Yuma County, where Miocene or Pliocene fossiliferous sediments are definitely older than the lavas of that vicinity (16, pp. 567–568). Most of them are definitely later than Cretaceous, although a few are post-Paleozoic and pre-Cretaceous, and in the Deer Creek coal field lavas are interbedded with Upper Cretaceous sediments. With these exceptions they have been assumed, from analogy with northern New Mexico and Nevada fields, where more definite dating is possible, to be predominantly middle Tertiary, with a feeble renewal of activity in Quaternary time.

Structure

Structurally, Arizona may be divided into two distinct regions—the Colorado Plateaus and the mountain and desert region.

In the Colorado Plateaus the structure is simple. The region has been elevated as a whole, with only minor folding, into a high tableland in which the sediments are essentially flat. At the west, toward the Basin and Range province, several normal faults of large throw, striking north, progressively step down the sediments to the west. These faults are largest in Utah. The most prominent are the Grand Wash and Hurricane faults. A general structure map of the area is shown by Darton (6, pl. 53, p. 14).

In the mountain area southwest of the Colorado Plateaus the predominating structural features are northwestward-striking anticlinal and synclinal folds. These folds were broken by normal and reverse faults into tilted blocks that stand at different altitudes, forming ridges and tectonic valleys or intermontane plains. The extrusive rocks have been deformed with the underlying basement rocks, thus dating the diastrophism as probably later than middle Tertiary. The northwest alinement of ranges and separating plains in central Arizona was superimposed upon an older east to northeast alinement closely associated with the larger intrusions that were accompanied by ore deposition. This earlier diastrophism, probably at the end of the Cretaceous, was separated from the later by a long erosion cycle. It was accompanied by much faulting but very little tilting or folding. In the southeastern part of the State, in the basin of thick Cretaceous sediments, the faults accompanying the larger intrusions trended northwest. Probably the early diastrophism was governed here by the trend of the thick Cretaceous sediments. The ages of the larger intrusives and later extrusives are the same here as in central Arizona. Diastrophism, confined almost exclusively to the Colorado Plateaus and bordering mountain area, was renewed in post-Pliocene time (later than the Gila conglomerate), resulting in the elevation of the two areas to their present altitudes and in their present youthful stage of erosion.

The structure developed during the early Mesozoic uplift has been little studied. In the Mule Mountains normal faults of large throw similar to the faults at the western edge of the Colorado Plateaus were developed (13, pp. 85–87). In the mountain area the Paleozoic and Cretaceous sediments differ little in attitude. Probably the late Permian or early Mesozoic uplift in the mountain area was of the plateau type.

In the desert region, southwest of the mountain area, the older structure is not so clear, owing to the nearly complete stripping of Paleozoic sediments. The sediments in the few outcrops available are much metamorphosed. Volcanism has also been extensive here, and the trend of the ranges is generally north to northwest but is broken in the north-central part by a belt about 50 miles wide of east-northeastward-trending ranges, coinciding with the possible pre-Cambrian Mazatzal basin and subsequent Paleozoic land ridge. Owing to the paucity of both Paleozoic and Mesozoic sediments in the region, little evidence exists as to the early Mesozoic diastrophism. Where present, the Mesozoic sediments differ greatly in attitude from the Paleozoic, and this difference, with the relatively greater metamorphism of the Paleozoic sediments, suggests that diastrophism was more violent in the desert region than in the mountain area during this pre-Mesozoic orogeny. The late Tertiary or Quaternary uplift of the mountain area and the Colorado Plateaus had little effect in the desert region. A few of the ranges, more notably those bordering the Colorado River, were uplifted on a comparatively small scale.

Geologic history

The incomplete evidence now available permits the following summary of the geologic history. At the end of the Paleozoic era the whole of what is now Arizona was raised above sea level. The Colorado Plateaus and the mountain area were probably raised as a unit. The present mountain area was raised higher than the bordering plateau and was considerably faulted but only slightly folded or tilted, whereas the plateau remained close to sea level and was the site of partly terrestrial and partly littoral sediments during most of Mesozoic time. In the desert region the mountain building may have been more vigorous, with tilting, folding, and possibly igneous activity. Toward the end of the Mesozoic era the sea invaded the southeastern part of the mountain area and desert region as a northwestward-trending arm, and a thick sedimentary series was deposited. The Laramide revolution, at the end of Mesozoic or in early Tertiary time, again lifted the present Colorado Plateaus and part of the mountain area as a block. This uplift was accompanied in the central part of the mountain area by faulting along northeast to east trends and much intrusion. The southeastern mountain and desert areas of thick Cretaceous sediments were at the same time more intensely folded and faulted along northwesterly trends, with much intrusion. During this period of diastrophism most of the ore deposits were formed. Erosion followed for a long period, terminated in mid-Tertiary time by extensive volcanism and renewed diastrophism along northwesterly axes in the present mountain and desert regions. High ridges and bordering valleys striking northwest were formed. The present plateau area was little affected and remained close to sea level. Another long period of erosion ensued during which the mountain ridges were much reduced and the valleys filled with thick detritus. The present mountain area and Colorado Plateaus were later raised essentially as a block, but the desert region was little affected. Minor renewed faulting took place, more especially along the borders of the plateau and in the desert region near the Colorado River. This uplift resulted in the present cycle of youthful erosion and the cutting by the Gila and Salt Rivers of their gorges through the mountain ridges.

Ore deposits

The copper deposits of Arizona may be classified in several ways, according to the criteria used. They fall into two age classes—pre-Cambrian, represented by the deposits of the Jerome and Bradshaw Mountains, and late or post-Cretaceous deposits, represented by all the others with the possible exceptions of the Bisbee deposits, which may be early Mesozoic, and of the Ajo and Williams River deposits, whose age is indeterminate. More exact dating is not possible, owing to the absence of fossiliferous sediments between Upper Cretaceous and late Pliocene or Pleistocene. In all the post-Paleozoic deposits the ore is associated with intrusives similar in type and in structural trend to others in New Mexico and Nevada whose age has been more definitely set as late Cretaceous or early and middle Tertiary. It has been assumed that the later Arizona deposits belong to the same metallogenetic epoch.

Under Lindgren's classification, based on temperature at the time of deposition, most of the important deposits are mesothermal, except possibly the Jerome, which may be in part hypothermal, and the Christmas and Silver Bell, which are hypothermal contact-metamorphic deposits.

Classified according to form, they fall into four classes—replacement veins, replacement pipes, limestone replacement deposits, and disseminated sulphide deposits. The replacement-vein type is represented by the Old Dominion and neighboring deposits at Globe, some of the Morenci deposits, and the Magma deposit at Superior. The replacement-pipe type is represented by the United Verde and United Verde Extension deposits of Jerome and the Bradshaw Mountain deposits. Limestone replacement is represented by the greater part of the Bisbee deposits, the deposits near Swansea in northwestern Yuma County, the contact-metamorphic limestone replacement deposits of Christmas, the Silver Bell deposits, and part of the Morenci deposits. The disseminated-sulphide deposits are represented at Miami, Ray, Ajo, Morenci (porphyry lode deposits and Clay disseminated ore body), Bisbee (Sacramento Hill), and Bagdad (in western Yavapai County).

All the economically important Arizona deposits are intimately associated in age and position with intrusive stocks, except possibly those at Jerome, whose

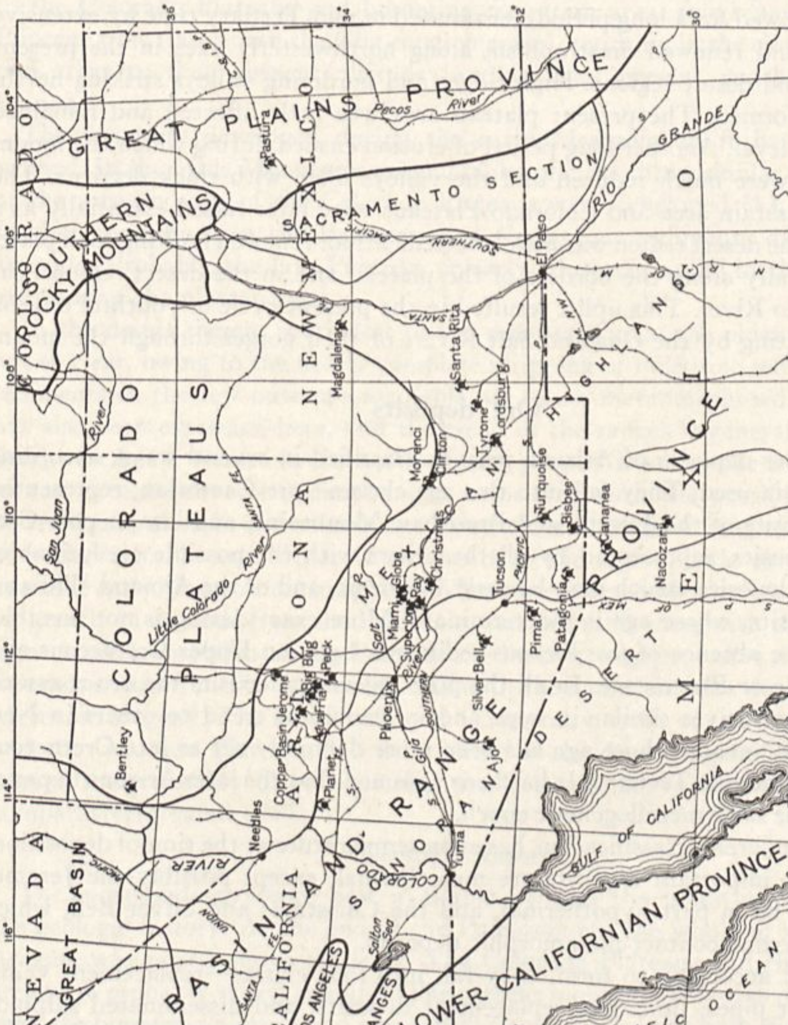


FIGURE 15.—Map showing general relation of copper-mining districts of the southwestern United States and northwestern Mexico to main physical divisions. (Physical divisions slightly modified from N. M. Fenneman.) Principal copper-mining districts indicated by crossed hammers.

age with reference to the adjoining diorite is more remote. The associated magmas are all intermediate to acidic and are typically represented by the pre-Cambrian United Verde diorite of Jerome, the post-Paleozoic Schultze granite of Globe, the quartz monzonite porphyry of Morenci, and the Sacramento Hill porphyry of Bisbee. The stocks associated with the ore bodies are predominantly apically truncated, as represented by the pre-Cambrian United Verde diorite at Jerome and the Mesozoic or early Tertiary intrusives at Globe, Morenci, Bisbee, Ray, Ajo, Superior, and Bagdad. In the Bradshaw Mountains the truncation of the Bradshaw granite and other pre-Cambrian intrusives associated with some of the ore deposits is low apical to medial.

All the large deposits known are in the mountain area except those of Ajo and the Williams River, which are in the desert region. None are within the Colorado Plateaus. (See fig. 15.)

The limestone replacement deposits, except possibly those on the Williams River, have replaced Paleozoic limestones, mainly of Mississippian and Pennsylvanian age and in minor part Cambrian and Devonian.

Jerome district [2]

History and production

The copper deposits of Jerome were discovered by United States Army scouts in 1875. Prospectors from Prescott and from farming settlements on the Verde River entered the district in the next few years. The principal locations were made by M. A. Ruffner. His interests and those of his backers were soon sold to Hugo Richards, of Prescott. Little other than the necessary location and assessment work was done until 1882, after the completion of the Atchison, Topeka & Santa Fe Railway, when Governor F. A. Tritle and associates obtained an option on the property and organized the United Verde Copper Co. Capital was raised in New York. A 42-inch water-jacket furnace was hauled to the mine from Prescott early in 1883, and the new camp was named Jerome, after the secretary-treasurer of the company. The rich surface ore was developed in the next 2 years to a depth of about 160 feet and was smelted to black copper rich in silver. The furnace was run until October, 1884, producing 4,669,000 pounds of copper and about $300,000 in silver. The venture was a financial success in its early years despite the transportation handicaps, and it paid one dividend of $60,000. The drop in copper prices late in 1884 caused suspension of work, and nothing further was done by the company other than to offer the property for sale. It was optioned in 1886 to Dr. James Douglas for Phelps, Dodge & Co. and, on the expiration of his option in 1888, to William A. Clark, of Montana. By this time transportation facilities had been greatly improved by the completion of the railroad from Ash Fork to Prescott. Clark reopened the mine and smelter and in 1892 began building a narrow-gage railroad from Jerome Junction, 17 miles north of Prescott, to the mine. This road was completed in 1894. The smelter was much enlarged and, in spite of the low copper prices of the early nineties, earned considerable profits.

The surface works were all built over the ore body, and this led to serious ground subsidence, aggravated by mine fires. In 1905 a start was made to remedy the adverse conditions, and in the next 10 years the ambitious plans of the company were put into effect. A modern smelter was built on the Verde River, the model town site of Clarkdale was constructed around it, the mine was connected to the smelter by a long haulage tunnel, the smelter and mine were con-

[2] This sketch is largely a condensation of previous reports on the Jerome district (4, 18, 19).

nected with the Ash Fork-Prescott railroad by a new broad-gage line from Cedar Glade, the mine was completely reequipped, and the surface plant was removed to a site safe from mine subsidence. The upper levels, which had been badly crippled by the mine fires, were opened by open-cut steam-shovel operations, entailing large expenditures in the removal of waste overburden. As a result production was tripled and costs greatly reduced. The mine has been developed many years ahead of production, insuring its long life.

The success of the United Verde Copper Co. attracted capital to the district almost immediately, but no new ore bodies were found other than the relatively small Iron King deposit, 3 miles southeast of the United Verde, until the revival in 1911 of the United Verde Extension Mining Co., first organized in 1900. The company was reorganized by James S. Douglas, son of Dr. James Douglas, and an active prospecting campaign was begun. After 3 years of discouraging work a small but rich chalcocite ore body was found which yielded a substantial profit and led into a large bonanza ore body in 1916. The company acquired a smelter site on the Verde River south of Clarkdale, sunk a second extraction shaft, drove a long haulage tunnel, and paid back the original investment manifold.

The spectacular success of the United Verde Extension encouraged many ventures in the district, most of which were unsuccessful. Small ore bodies were found by the Jerome Verde Copper Co., the Verde Central Mines Co., the Dundee-Arizona Co., the Copper Chief Mining Co., and the Shea Copper Co., the first two of which were absorbed later by the United Verde Extension and the United Verde, respectively.

Metal production in Jerome district

Period	Mine	Copper (pounds)	Gold (ounces)	Silver (ounces)	Total value
1883–87	United Verde Copper Co. (early production).	4,669,000	....	237,900	$1,071,100
1888–1914	United Verde Copper Co. (early production, Clark régime).	696,932,800	397,300	11,854,500	116,185,500
1915–29	United Verde Copper Co. (recent production).	1,188,150,900	532,900	18,871,300	225,867,500
1915–29	United Verde Extension Mining Co.	598,728,700	91,500	4,809,900	112,779,100
1904–5	Equator Mining & Smelting Co.	1,300,000	....	....	184,600
1900–20	Jerome Verde Copper Co...	1,484,300	500	14,700	344,500
1916–23	Copper Chief mine........	....	27,000	415,600	901,800
1929	Verde Central Mines Co....	4,335,300	....	19,800	773,500
		2,495,601,100	1,049,200	36,223,500	458,107,600

Total dividends approximately $116,600,000.

Topography

The ore deposits of Jerome are in the Black Hills, a northwestward-trending range in the north-central part of the State. The boundaries of the range are indefinite, as it merges to the northwest with the Colorado Plateaus. Its southeast end is also indefinite. Its length from Cherry Creek to Bodkin, 5½ miles northwest of Jerome, is about 17 miles, and its width averages about 7 miles.

The range is bounded on its northeast side by a broad depressed basin about 8 miles wide, through which meanders the Verde River. The altitude of the river at Clarkdale is 3,400 feet. Northeast of the Verde River Valley the steep slopes and cliffs of the Verde Breaks mark the edge of the Colorado Plateaus, which have here an average altitude of about 6,000 feet. Southwest of the range is the relatively high Lonesome Valley, now being trenched by Agua Fria Creek. The altitude of the creek at Yaeger siding is about 4,800 feet. The range rises steeply to a central high dissected mesa, which varies in width from a quarter of a mile at the south end of the range to 4 miles at Mingus Mountain (4 miles south of Jerome), where it attains 7,720 feet above the sea. The town of Jerome is on the northeast slope, about 4 miles from the northwest end of the range. The post office in Jerome is 5,150 feet above sea level, 1,750 feet above the Verde River at Clarkdale, and 2,050 feet below the crest of Mingus Mountain.

The district is served by an 11-mile broad-gage railroad from Clarkdale, which is connected to the Verde River branch of the Santa Fe Railway at Drake. A paved highway connects Jerome and Clarkdale, and a surfaced road through a high pass north of Mingus Mountain connects Jerome with Prescott, the county seat of Yavapai County.

Rocks of the district

The oldest formation exposed in the Jerome district is a phase of the pre-Cambrian Yavapai schist, here a predominantly schistose greenstone derived from basic to intermediate extrusive rocks. The greenstone complex includes much partly intrusive quartz porphyry, somewhat less sheared than the greenstones. The prevailing schistosity strikes N. 20° W. and dips steeply. These pre-Cambrian rocks crop out as a triangular area with the apex about three-fourths of a mile northwest of Jerome. The area extends southeastward about 11 miles along the northeast slope of the range, where, at its southeast end, its width is about 2½ miles. Here the schist is intruded by a large mass of granite, probably a phase of the Bradshaw granite of the Bradshaw Mountains quadrangle (4, p. 16). Resting on a baseleveled surface of schist, diorite, and granite are Paleozoic sediments about 1,000 feet thick. At the base is 80 feet of sandstone, the top of which contains Upper Devonian fossils, followed by 500 feet of thin-bedded sandy limestone of Upper Devonian age, overlain by 250 feet of massive Mississippian limestone which corresponds with the Redwall limestone of the Grand Canyon. The Redwall limestone is capped at Mingus Mountain by an erosion remnant of Supai shale, of upper Carboniferous age, about 200 feet thick.

Resting on a deeply trenched surface of all the older rocks is a covering of Tertiary basalt derived from vents in the Colorado Plateaus. Its maximum observed thickness is 700 feet.

In the Verde River Valley is exposed a 1,500-foot succession of Tertiary lacustrine sediments later than the earliest basalt flows. Above these are alluvium and terrace gravel, to a maximum height of 1,000 feet above the river. In the upper workings of the United Verde Extension mine is a pre-basalt conglomerate, several hundred feet thick, cemented by limonite and calcite and partly impregnated with chrysocolla, melaconite, and malachite.

The Yavapai schist is cut by a small diorite stock, which forms the hanging wall of the United Verde ore body. Its elliptical outcrop is about three-quarters of a mile by half a mile, and the stock dips about 70° NW., roughly following the contact of the greenstone and rhyolite phases of the schist. According to Lindgren (4, pp. 57–58), it is a dark-green medium-grained rock composed of about equal parts of augite and feldspar, with more or less chlorite and epidote. Though somewhat deformed, it is rarely schistose except near the contacts. The feldspar, probably originally andesine or oligoclase, has been saussuritized—that is, converted to an aggregate of zoisite and albite. The feldspars were also somewhat sericitized. The pale augite is extensively altered to chlorite with much epidote and some actinolite.

Structure

The Paleozoic sediments lie virtually flat beneath the basalt cover. At the northwest end of the mountains the basalt caps Supai shale, whereas at the southeast end it rests on the Devonian limestone, testifying to the pre-basalt erosion. At the United Verde Extension mine there is a pre-basalt canyon several hundred feet deep, as is shown by the occurrence of a pre-basalt conglomerate above the ore body where the Paleozoic sediments were stripped and by the presence 900 feet to the north, at the Edith shaft, of 490 feet of Paleozoic sediments below the basalt. The impregnation of the conglomerate by copper salts suggests that the pre-basalt canyon had exposed the United Verde ore body. Possibly the line of limestone cliffs on the northeast edge of the mesa capping the range may correspond closely with the southwest edge of the pre-basalt canyon, so that the present cycle of erosion has done little more than strip the basalt and underlying conglomerate. The present relations of the range and the accompanying depression of the Verde River Basin result from post-basalt normal faulting along northwesterly trends, exemplified by the Verde fault, which runs through the town of Jerome, strikes N. 50° W., and dips about 60° NE. The total vertical slip on this fault, computed from the dislocation of the pre-Cambrian peneplain, is about 1,700 feet. Toward the northwest the fault splits, and the several branches finally die out within the Colorado Plateaus. Other parallel faults of large throw occur northeast of the Verde fault.

The Black Hills are on the north edge of the pre-Cambrian Mazatzal Basin and land ridge. (See p. 170.) Prior to the deposition of the Mazatzal quartzite the old lava and sandstone complex had been metamorphosed by diastrophic forces into a schist striking north-northwest to west, with steep dips. The schist at the center of the mining district is made up largely of sheared rhyolite with minor chlorite schists derived from more basic extrusives and a little schist of sedimentary derivation. After the metamorphism the area was worn to a peneplain on which the Mazatzal quartzite was deposited. Subsequently it was folded, elevated, and again eroded, and a large part of the quartzite was removed. Undulating movements took place during late Proterozoic and Cambrian time, and the area was finally reduced to low relief during late Devonian time.

At some time after the development of the schist and before the late Devonian, the district was invaded by diorite and granite masses, with which the mineralization was probably connected. The diorite that forms the hanging wall of the

United Verde ore body at Jerome intruded the schist as a stocklike mass along the contact of the rhyolite and earlier greenstone. The schistosity of the rhyolite is accentuated near the contact. The principal path for the mineralizing solutions was the southeast edge of the diorite, near which the schist was altered and replaced by metallic sulphides. Ransome (17, pp. 20–21) has shown that movement on the Verde fault took place after the ore deposition and before the pre-Devonian peneplanation. This movement was probably several thousand feet and divided the original ore body into two segments. It indicates at least one period of major diastrophism after the ore deposition and in pre-Devonian time. Erosion and attendant oxidation developed a surface of low relief on which were exposed the gossans of the two ore segments now known as the United Verde and United Verde Extension ore bodies. Subsidence subsequently lowered the area below sea level in late Devonian time. Further displacement on the Verde fault occurred in late Tertiary time.

Ore bodies

Two large ore bodies, the United Verde and United Verde Extension, and three smaller ones, the Equator-Copper Chief, Verde Central, and Dundee-Arizona, are known in the district.

United Verde

The United Verde ore body, which has produced most of the ore of the district, crops out about a quarter of a mile northwest of Jerome. It is in the footwall of the Verde fault (see fig. 16), which passes about 800 feet to the east. Below the weathered zone the ore body is a cylindrical pipe of massive pyrite, chalcopyrite, and zinc blende, within and on the edges of which are lenses carrying higher percentages of chalcopyrite. The pipe is roughly elliptical in cross section, with dimensions of 800 by 700 feet, and dips steeply to the northwest. The average grade of the massive pyritic material exclusive of the higher-grade ore lenses is about 1 percent of copper, and the average grade of ore mined is between 5 and 6 percent. The pipe has been developed to a depth of more than 3,000 feet without showing signs of diminution either in size or in copper tenor. The average stoping area on four representative levels (4, p. 70) is about 49,000 square feet, about 11½ percent of the total pipe area of about 421,000 square feet. The massive sulphide ore within the pipe consists of fine-grained aggregates of pyrite and minor quantities of sphalerite, chalcopyrite, arsenopyrite, and tennantite in a gangue of quartz, dolomite, and chlorite. All these minerals represent replacement, mainly of schistose rhyolite porphyry and less commonly of chert and slate. Most of the ore is apparently massive sulphide, but along the borders of the ore bodies all stages of transition are recognizable. Many of the ores still contain the quartz phenocrysts of the original rhyolite porphyry (4, pp. 71–72). The United Verde diorite forms the hanging wall of the ore body, and schistose rhyolite porphyry the footwall. Contacts with the diorite are sharp, and only locally does it contain even traces of disseminated pyrite. The massive sulphide grades rapidly into unreplaced rhyolite. In places along the diorite contact is red chalcedonic jasper containing disseminated pyrite, sphalerite, and specularite, the specularite replacing all the other minerals. On the footwall or rhyolite side of

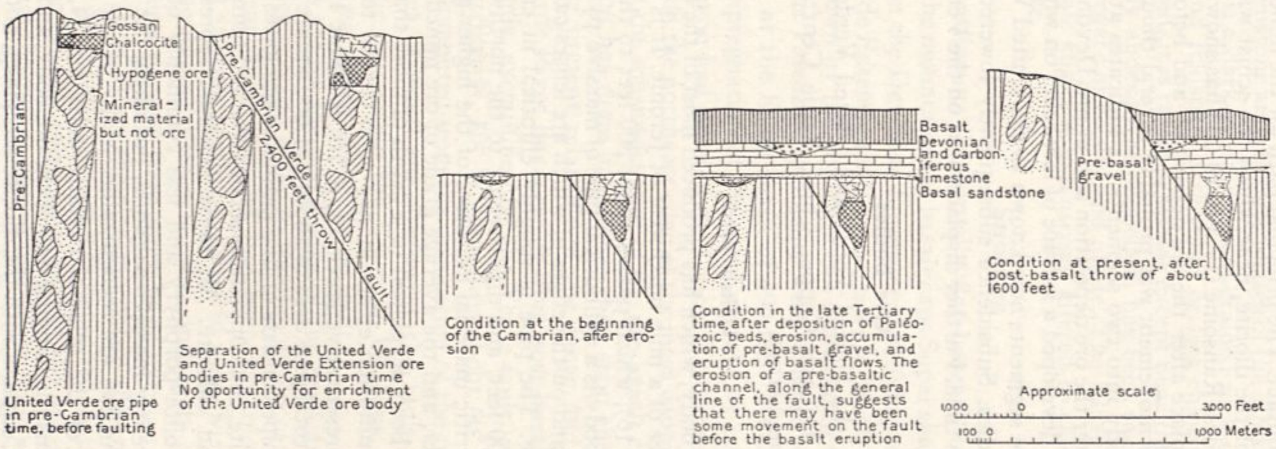


FIGURE 16.—Probable stages in the faulting of the United Verde and United Verde Extension ore bodies, Jerome district, Arizona. (After F. L. Ransome, 16th Internat. Geol. Cong. Guidebook 14, pl. 4.)

the ore body a special type of ore is found in which the gangue is ferriferous black chlorite and the percentage of chalcopyrite is higher than within the pipe.

The paragenesis of minerals in the ores is as follows: Much of the quartz is residual from the replaced schist. Quartz deposition by the mineral solutions began early and continued with decreasing intensity after the last of the sulphides. Sericite is common and has replaced both quartz and primary feldspar. Chlorite is intergrown with sericite. Ferriferous chlorite associated with chalcopyrite in the "schist ores" is later than the other gangue minerals. Pyrite occurs as minute cubes or aggregates replacing the earlier quartz and was usually shattered and minutely fractured before the deposition of the other sulphides. Arsenopyrite occurs sparingly but generally and is a little later than pyrite. Sphalerite, a pale-green iron-free variety, is abundant and later than pyrite. It is in places alined in parallel streaks with later quartz and ankerite. Chalcopyrite is of about the same age as sphalerite but usually slightly later and has replaced all the earlier minerals, particularly the shattered pyrite. Tennantite, the latest metallic mineral, is accompanied by dolomitic coarse-grained gangue, much of it as veinlets in the ores. Supergene minerals in the upper levels include calcite, "limonite," abundant gypsum, chalcocite, and cuprite. In the "schist ores" the chalcopyrite and sphalerite occur in large crystals and aggregates with less abundant pyrite and much associated ferriferous black chlorite (4, pp. 73–74).

The oxidized ore and original outcrop have been almost entirely mined out. Fortunately a good description of the now vanished rich oxidized ore outcrop is preserved in a report made by George W. Maynard, in 1879, to Gen. John C. Frémont, then governor of the Territory. Extracts of the report are in Frémont's report of November 20, 1879, to Carl Schurz, Secretary of the Interior. Maynard described the face of a tunnel 80 feet below the outcrop as an irregular "crevice filled with highly ferruginous clay bedding huge boulders of ore." The ore "boulders" he described as malachite with veins of copper glance and cuprite. Selected samples assayed from 36.60 to 57.88 percent of copper and from 1.21 to 6.05 ounces of silver to the ton. One small mass of "pyrites" assayed 4.88 percent of copper and 49.84 ounces of silver to the ton. Frémont reported that the 80-foot tunnel had demonstrated a width of at least 40 feet of high-grade oxidized ore with a length of over 142 feet. At a depth of 160 feet the oxidized ores had almost entirely given way to primary sulphides without any well-marked chalcocite zone. From this level down to the 600-foot level the sulphides, although essentially unenriched, contain thin veinlets and films of chalcocite. Below the 600-foot level no effects of supergene solutions are seen except along the so-called "watercourses" following highly altered narrow dikes, probably of diorite porphyry, intruded after ore deposition in pre-Devonian time.

The ore outcrop is 500 feet lower than the contact of the schist and Paleozoic sandstone on the hill west of the mine. The pre-Devonian gossan was eroded either in pre-basalt time, in post-basalt pre-fault time, in the present erosion cycle, or in all three of these periods. From analogy with the United Verde Extension occurrence, where the pre-Devonian conditions are virtually intact, a deep chalcocite zone probably existed, the bottom of which may have been represented by the rich oxide ore described by Maynard. The oxidized ore described by Lindgren (4, p. 75) represents leaner siliceous marginal ore left in the earlier operations and now mined for its special value as flux.

The main features of occurrence of the United Verde ore body are summarized below, in connection with the United Verde Extension.

United Verde Extension

The United Verde Extension ore body does not crop out and was not found until 1916, 41 years after the discovery of the United Verde ore body. It is 7,000 feet east-southeast of the outcrop of the United Verde, on the hanging-wall side of the Verde fault, and is overlain by Tertiary conglomerate and basalt. The post-basalt vertical movement on the fault was about 1,700 feet, down to the northeast. The pre-Devonian outcrop, about 700 feet below the present surface, consists of a thoroughly leached siliceous gossan containing almost no trace of copper. It is elliptical, about 500 feet long by 300 feet wide, and is composed of dense siliceous, cherty material, much of it red from hematite and partly cellular from the leaching of the sulphides. Enrichment in silver is distinct just above the massive sulphides. Although the average chalcocite ore contains less than 2 ounces of silver to the ton (considerably less than the ore of the United Verde), the material for about 7 feet above the sulphide ore contains from 10 to 12 ounces and locally as much as 100 ounces to the ton (4, pp. 85–86). The Edith shaft, 900 feet north of the ore body, penetrates 180 feet of lava, 400 feet of limestone, and 90 feet of Tapeats sandstone, reaching the pre-Cambrian at 678 feet (4, p. 80). The bottom of the leached ground is about 50 feet below the "1,200-foot" level, 1,128 feet below the collar of the shaft, making the thickness of leached capping about 450 feet below the pre-Devonian surface. The Paleozoic rocks had been stripped during the pre-basalt erosion period from above the leached capping, which is immediately overlain by conglomerate and volcanic agglomerate. Supergene copper and iron have impregnated parts of this material sufficiently to make commercial ore, and several thousand tons has been mined between the 700-foot level and the surface.

The leached capping is underlain with sharp contacts by the main body of chalcocite ore, parts of which were bonanza ore bodies. Narrow streaks of chalcocite ore extend above the main ore body as far as the 1,100-foot level, 978 feet below the shaft collar and 300 feet below the pre-Devonian surface. The rich main ore body below the capping is about 440 by 269 feet in plan, extending nearly vertically to the 1,400-foot level (150 feet below the capping). It then tapers gradually and approaches the Verde fault but again slopes east without reaching it (4, p. 84). It continues to pitch eastward away from the fault to the 1,700-foot level, where it is considerably smaller and the ore consists of massive pyrite with much less chalcocite. The richest ore is on the 1,400-foot level, where the chalcocite core stoped to a grade of about 24 percent. The core grades marginally into leaner pyritic ore. Two schistose and mineralized streaks about 150 feet apart, trending N. 20° W., extend from the ore body. One of these, on the 1,200-foot level 500 feet south of the shaft, extended about 120 feet horizontally and reached a little above the 1,100-foot level but was not found on the 1,400-

foot level. Another of the smaller ore bodies was near the Jerome-Verde line, 500 feet west of the Edith shaft, in greenstone schist on the 1,200-foot level. Several fissures trending N. 45° W., parallel to the Verde fault, were crossed. In June, 1922, the drift showed 6 feet of ore containing chalcocite, cuprite, and native copper and averaging 40 percent of copper. The ore body here trends nearly north, and the adjacent rock is reddish and soft, partly oxidized quartz porphyry. The Verde fault is 300 feet to the west. Northwest of the main ore body lenses begin. The first (on the 1,400-foot level) comes within 40 feet of the main ore body and contains chalcocite and native copper. On the 1,300-foot level this lens is 400 feet long and 5 to 40 feet wide, and the ore averaged 40 percent of copper. The lens was stoped up to the 1,100-foot level but narrowed there. The rake is northwest.

In the lower levels, where oxidation was less, the prevailing wall rock is greenstone schist intruded in places by quartz porphyry. Quartz porphyry lies beneath the ore body where it approaches the fault and elsewhere. Apparently the big ore body is almost wholly in this rock. Kaolinization was intense at the edges of the ore body. Diorite is known only in a small area on the 1,200-foot level (4, p. 82). The pronounced schistosity of both the greenstone and the porphyry trends about N. 20° W.

The gangue is fine-grained cherty quartz with a little later calcite. There is much pyrite, which in the hand specimens is almost entirely concealed by chalcocite but on polished surfaces appears about as plentiful as in pyritic ore from the United Verde mine. The pyrite is much shattered, and the chalcocite has the same relative position as the chalcopyrite and zinc blende in the United Verde ore, although the pyrite grains are here more rounded. Native copper is abundant, especially in the tops of the northwest lenses. No chalcopyrite or sphalerite is found except a few feathery microscopic secondary chalcopyrite crystals on the edges of massive chalcocite. The chalcocite is prevailingly sooty, but some is massive.

The ore body itself does not reach the Verde fault. The leached capping reaches the fault on the 1,200-foot level, where drag of chalcocite occurs along the fault (4, p. 84). Possibly the capping reaches the fault elsewhere between the 1,250- and 700-foot levels.

Both the United Verde and United Verde Extension ore bodies are pipelike replacement deposits of pre-Devonian age in greenstone schist and subordinate rhyolite porphyry. In the United Verde, the larger ore body, the present cycle of erosion has practically stripped the original leached capping and probable chalcocite zone, whereas in the United Verde Extension both of these zones are preserved virtually intact. If the original chalcocite zone of the United Verde is represented by the oxidized outcropping ore, which bottomed at a depth of about 160 feet, the combined original capping and chalcocite zone was not over 660 feet thick. In the United Verde Extension the chalcocite zone is 450 feet and the leached capping 450 feet thick, a total of 900 feet. On the assumptions that the United Verde enriched ore, of about 15 percent average grade, was derived from 6 percent protore (the average of the United Verde combined chalcopyrite and zinc blende for the total pyritic pipe) and that the efficiency of enrichment was nearly complete, the 450 feet of enriched ore in the United Verde Extension would have been derived from 900 feet of overlying ore, of which 450 feet is represented as capping, indicating at least 450 feet removed by pre-Devonian erosion. With an original thickness of capping at the United Verde of 450 feet, the total thickness of enriched ore was not over 200 feet, which on the same assumptions would indicate nothing removed by erosion. On these assumptions the total vertical dimension of the original unfaulted pipe down to the lowest explored level was about 4,850 feet. Inasmuch as a large part of the copper in the old ground waters was doubtless dissipated, probably much more of the pipe was eroded, and the original vertical dimension was well over a mile. The difference in chalcocitization of the two ore bodies may be explained either on the assumption that oxidation was well under way in the United Verde Extension segment (the top of the pipe) before the pre-Devonian faulting, or by differences in composition of the two parts of the pipe, possibly an increase of dolomite in the gangue with depth.

Equator-Copper Chief

The outcrop of the Equator-Copper Chief ore body, on the southwest side of the Verde fault and about 3 miles south-southeast of Jerome, is divided between the Iron King mine of the Equator Mining & Smelting Co. and the Copper Chief mine. The deposit appears to lie in an east-west shear zone between a flat-lying granite porphyry and only slightly schistose greenstone cut by several porphyry dikes striking north. The ore was oxidized for 230 feet below the collar of the Copper Chief shaft, and primary massive pyrite and chalcopyrite underlie the capping. The sulphide zone is almost entirely within Equator ground. A considerable tonnage was mined and smelted locally by the Equator company in 1905. The oxidized zone in Copper Chief ground is siliceous and contains copper carbonate and sporadic cerusite. Parts of it constitute a silver-gold ore with 0.3 ounce of gold and 6 ounces of silver to the ton. A large tonnage was mined by the Hayden Development Co. in 1922 and treated at a cyanide plant on the ground. The production of the two operating companies is shown on page 180.

Verde Central

The Verde Central ore body, about a mile southwest of Jerome, on upper Deception Gulch about 5,600 feet above sea level, is associated with a siliceous vein that cuts greenstone on the contact of more or less schistose quartz porphyry. The vein strikes N. 45°–60° W. and dips 60° NNE. The schistosity strikes N. 20° W. The vein on the outcrop is iron-stained and siliceous, with some malachite, and has been followed to a vertical depth of 1,950 feet. Oxidation is shallow, and the ore deposits are lenses of disseminated chalcopyrite and pyrite in much silicified schist on both sides of the vein. The lenses range from 10 to 40 feet in width and are several hundred feet long. The ore mined in 1929 ran more than 2 percent of copper. It was treated at a 300-ton flotation mill at the mine, and the concentrates were hauled to the Clemenceau smelter of the United Verde Extension Mining Co. for treatment. The mine was purchased by the United Verde Copper Co. in 1930 and is not operating. The production is shown on page 180.

Dundee-Arizona

The Dundee-Arizona ore body and those of the United Verde Extension in the pre-basalt conglomerate are the only Tertiary ore bodies in the district. The ground lies in Deception Gulch north of the United Verde Extension and northeast of the Verde fault. The ore body is in an old post-basalt, pre-fault stream bed. The gravel contains basalt and limestone boulders, some as large as 2 feet in diameter, together with iron-stained quartz and jasper boulders probably derived from the United Verde outcrop. The conglomerate is unevenly impregnated with limonite and a blue-green chrysocolla, coating and partly replacing the boulders and cementing sand. The impregnation extends to a depth of about 5 feet, and considerable low-grade oxidized copper ore has been developed. Experimentation looking toward leaching the ore has been done, but little production has been made. The ore resembles that mined by the United Verde Extension in pre-basalt gravel beds. The impregnation by siliceous sulphate solutions has replaced the underlying limestone to a slight extent along fractures in the limestone.

Globe-Miami district [3]

History and production

The mineral district centered around the towns of Globe and Miami was first seen by Army men during expeditions sent against Apache Indians. No prospecting was done until 1872, when parties from Florence, the nearest permanent settlement, entered the district and made the first locations on copper lodes near Globe. In 1873 rich silver croppings were found at McMillen, 12 miles north of Globe. The district adjoined the chief Indian settlements, and the peace treaty of 1872 was kept by only a part of the tribes, hence little work was possible until 1878, when hostilities virtually ended. The Southern Pacific Railroad was completed from Los Angeles to Casa Grande in 1878. Active work on the silver lodes started in 1879, but the deposits were all superficial and were quickly exhausted, and all work on them ceased by 1893.

The copper croppings were first worked in 1881, after the completion of the railroad made possible easier transportation by way of the San Simon and Gila River Valleys. Several companies were organized, and small blast furnaces were erected to treat the richest hand-sorted ore. By 1883 two strong companies, the Old Dominion Copper Mining & Smelting Co. and the Buffalo Mining & Smelting Co., had by purchase and location absorbed the others. The Buffalo company was purchased in 1887 by Phelps, Dodge & Co. and was thereafter operated as the United Globe Mining Co.

Both companies were operated at a gradually expanding rate until 1895, when the Old Dominion Mining & Smelting Co. was purchased by Boston interests. The Gila Valley, Globe & Northwestern Railroad from Bowie, on the main line of the Southern Pacific, was built into Globe in 1898. This railroad enormously stimulated activities. New and larger smelters were erected, and the mines were

[3] This account is in the main condensed from publications by Ransome (20, 22), with additions to bring the description of the ore deposits up to date.

developed to greater depths, necessitating the first large pump installations to take care of the heavy flow of water encountered. At the beginning of the 20th century both companies passed into the control of Phelps, Dodge & Co., who operated them through a holding company, the Old Dominion Co. Operations were further expanded, and new companies entered the Globe end of the district, the most successful of which were the Arizona Commercial, Iron Cap, and Superior & Boston, which after refinancing developed into successful producers.

The Old Dominion and the smaller mines near Globe continued to produce until 1930, when, on the exhaustion of the higher-grade ore, they were closed indefinitely.

At Miami, 7 miles west of Globe, the first serious work was done in 1896, when the Black Warrior Copper Co. exploited the Black Copper group, a large cropping of siliceous oxidized ore. After 13 years of unsuccessful attempts to beneficiate the ore by combined concentration, leaching, and smelting, the ore was mined and shipped direct to various smelters as siliceous flux. The property was absorbed by the Inspiration Consolidated Copper Co. in 1920. Material from other similar oxidized deposits was also shipped for flux in the late nineties and the early years of the 20th century. The largest producers were the Live Oak and Keystone, both later absorbed by the Inspiration Consolidated Copper Co.

The first work on low-grade disseminated sulphides was done in 1904, when the Inspiration Mining Co. was organized to develop a small group of claims. This company, after developing a fair tonnage of 3 percent ore, erected a 50-ton concentrator in 1906. The venture was not a success, as the scale of operations was too small.

In 1905 a small group of claims adjoining the Inspiration group was optioned by the General Development Co. After a year of discouraging work, a body of 3 percent disseminated chalcocite ore was found which later proved to exceed 5,000,000 tons. The Miami Copper Co. took over the property and started a 3,000-ton concentrator, the first unit of which went into commission in 1911. Concentrates were at first shipped to Cananea, Mexico, for smelting.

The Inspiration Copper Co., which purchased the holdings of the Inspiration Mining Co., added a large group of claims. In 1912 it absorbed one of the smaller companies known as the Live Oak Development Co., and a reorganization was effected as the Inspiration Consolidated Copper Co. The mine was thoroughly equipped, and an 18,000-ton concentrator was built. The first concentrates were produced in February, 1915, on the eve of the extraordinary World War copper market.

The International Smelting Co. entered the district in 1913 and began a smelter, which was completed in 1915.

The two large companies continued operations, and the Inspiration added to its reserves by purchase of several additional groups, until 1923, when the better-grade reserves were approaching depletion. The Miami Copper Co. then by modification of its mining and milling technique was able to add a large tonnage of very low grade ore to the reserves. The Inspiration Consolidated Copper Co. successfully experimented with a leaching process to treat a large tonnage of partly oxidized ore, constructed a 9,000-ton leaching plant, and on its completion, in 1926, closed the concentrator. Both companies ceased operations in 1931, owing to the drop in the copper market.

The only other successfully producing property was that of the Van Dyke Copper Co., which demonstrated, by drilling in 1917, the existence of oxidized ore in schist below a thick conglomerate cover. In 1928 a shaft, sunk in 1917, was unwatered, and a large body of oxidized ore was soon developed. This ore was actively worked, and regular shipments were made in 1929 and 1930, but since that time the property has been inactive.

The district has over 20 years' supply of ore blocked out that can be beneficiated at a low cost but is now virtually idle pending more favorable market conditions.

Metal production of Globe-Miami district

Period	Source	Copper (pounds)	Gold (ounces)	Silver (ounces)	Total value
1878–93	Early silver mines.....	....	....	3,040,000	$3,650,000
1883–95	Early copper (Globe)..	67,514,758	....	100,000	8,898,289
1896–1929	Recent copper (Globe).	835,620,688	112,686	7,964,702	150,032,269
1899–1929	Miami-Inspiration....	2,162,610,714	....	....	374,675,954
1904–29	Miscellaneous........	13,199,792	....	....	2,239,338
		3,078,945,952	112,686	11,104,702	539,776,922

Total dividends paid, $104,256,167.

Topography

The district is in the mountain area close to the Colorado Plateaus. It is divided into two parts, served respectively by the towns of Globe and Miami, about 8 miles apart, on the two sides of the north end of a broad northwestward-trending intermontane plain. At its north end this plain, which extends southeastward for over 140 miles, is drained by Pinal Creek, a northwestward-flowing tributary of the Salt River, into which it flows about 4 miles east of the east end of Roosevelt Lake. The plain is filled with detritus from the bordering mountains and is now in part being trenched. The plain at Miami Flat, between Globe and Miami, is about 3,350 feet above sea level. It is here bordered on the northeast by the Globe Hills, a highly dissected range 8 miles long by about 5 miles wide, rising to a maximum altitude of about 5,000 feet above sea level. In these hills are the earlier-worked copper mines. The Globe Hills are separated by low-lying ground from a second highly dissected northwestward-trending range in which are the silver mines of the district, 12 miles north of Globe.

The western (Miami) end of the district is on the northeastern slopes of the highly dissected Pinal Mountains, a northwestward-trending range southwest of the intermontane plain. The Pinal Range rises to a maximum altitude, at Barnes and Webster Peaks, of over 5,500 feet above sea level and merges imperceptibly on the west into a high dacite-covered plateau 8 to 10 miles wide.

The district is connected with the main line of the Southern Pacific Railroad at Bowie by the Gila Valley, Globe & Northwestern Railroad.

Rocks of the district

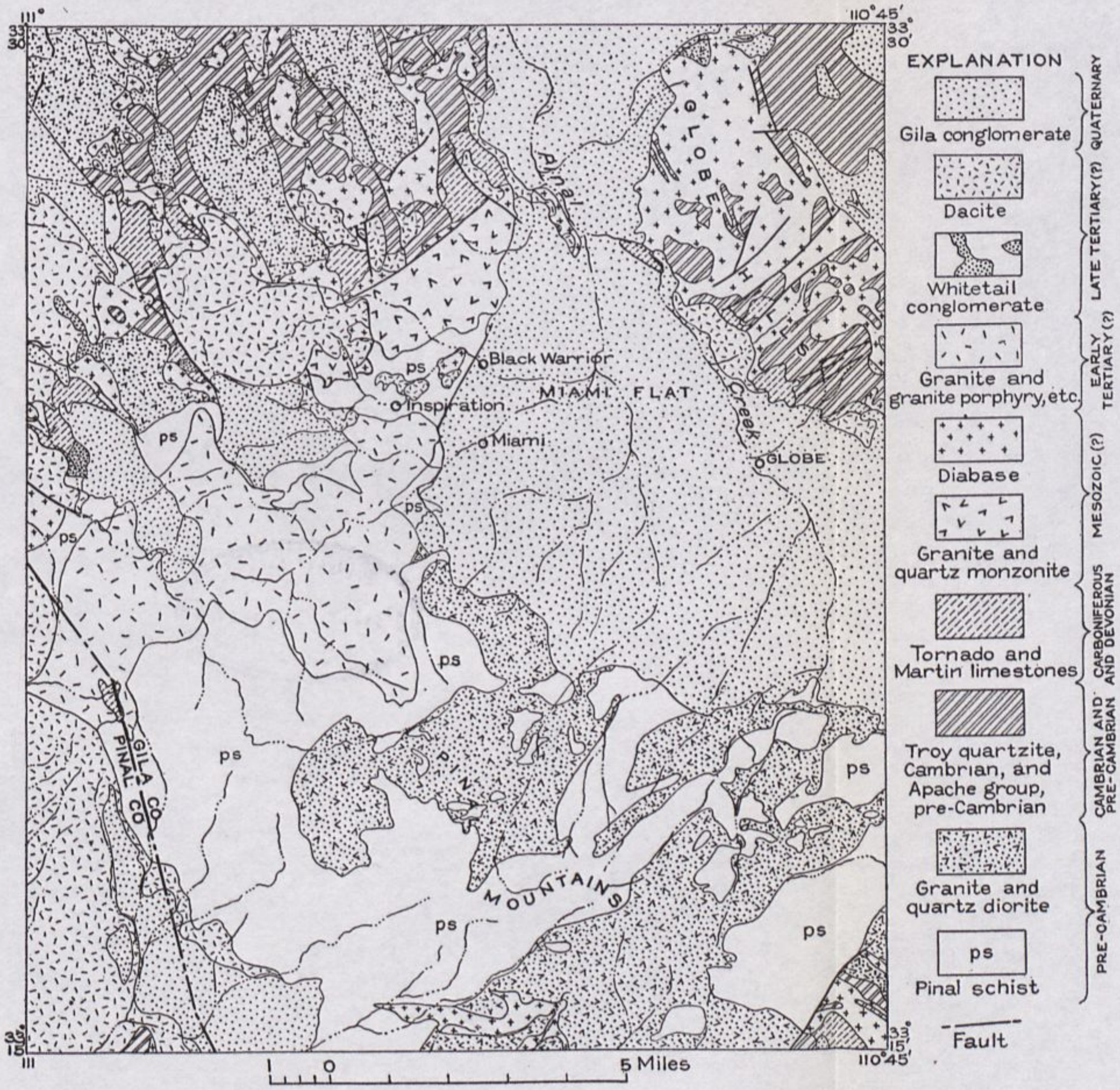
The basement rock is pre-Cambrian schist derived essentially from arenaceous sediments and minor intrusive and extrusive rocks. (See pl. 8.) In texture the varieties range from very fine grained, slaty sericitic schist to imperfectly cleavable, coarsely crystalline quartz-muscovite schist carrying locally andalusite or sillimanite. A few layers of green amphibolitic schist are associated (20, p. 33). The schistosity strikes generally northeast, and the dip ranges from 45° to vertical. As a rule the schistosity is roughly parallel with whatever larger banding due to difference in the composition of the schists may be discernible, probably indicating that the schistosity is approximately parallel with the original bedding (20, p. 34). The composition of the schist corresponds closely to that of an impure shaly sandstone. The schist has been named "Pinal" by Ransome, from its type exposures in the Pinal Mountains.

The schist was intruded in pre-Cambrian time by quartz diorite and granite in areas outside the mineral belts. These intrusives are characterized by incipient granulation, generally coarse texture, and deep weathering, especially near the sedimentary contacts with the overlying Proterozoic conglomerate or shale.

In the mineralized areas a peneplaned surface of schist is overlain by about 865 feet of Proterozoic sediments, the Apache group. The coarse Scanlan conglomerate, which averages about 10 feet in thickness but is commonly absent, is the basal member of the group. Above the conglomerate is the Pioneer shale, consisting of about 150 feet of arkosic shale. The shale is overlain, apparently conformably, by the Barnes conglomerate, from 10 to 55 feet thick, and this in turn by about 450 feet of Dripping Spring quartzite, generally fine-grained and varicolored. The partings between the Dripping Spring beds are indistinct, and the whole formation is intensely indurated. The quartzite is in turn overlain by 225 feet of iron-stained dolomitic cherty-banded limestone, the Mescal limestone, which in the district is generally capped by 25 to 75 feet of fine-grained vesicular basalt. The Apache group is devoid of fossils and, though originally tentatively assigned by Ransome to the Cambrian and possibly Ordovician and Silurian, has been proved beyond doubt in other areas to be older than middle Cambrian (21) and to be separated from the overlying sandstone by an unconformity of considerable magnitude. Darton assigned the group to the late Proterozoic and tentatively correlated it with the Unkar beds of the Grand Canyon series (6, pp. 27–37).

The basalt in the district is overlain, locally with an intervening thin basal conglomerate or breccia, by the Troy quartzite, 400 feet thick, which is generally cross-bedded and pebbly and grades at the top into shaly beds with abundant worm casts. Middle Cambrian fossils have been found in the formation elsewhere in the State (21).

The Troy sandstone or quartzite is overlain without apparent unconformity by thin-bedded fossiliferous dolomitic limestone, the Martin limestone (Upper Devonian). Then follows massive pure Mississippian limestone, which grades imperceptibly into similar beds carrying Pennsylvanian fossils. The exact thickness of the Mississippian has not been determined, and only a small part of the



GEOLOGIC MAP OF THE GLOBE-MIAMI DISTRICT, ARIZONA

After F. L. Ransome.

limestone, which nearby is at least 1,000 feet thick, has been preserved in the district.

The only other sedimentary rocks in the district are the Whitetail and Gila conglomerates, of probable late Tertiary age. The Whitetail, only small remnants of which are found in the district, is separated from the Gila by dacite lava flows. Both were laid down on a rough erosion surface, and both are made up of poorly assorted, partly rounded material and can be classed as fanglomerates. The Gila conglomerate varies greatly in thickness and lithology. It is mainly a valley filling in the intermontane plain between the Globe and Pinal Ranges but is also found as erosion remnants well up the slopes of the mountains, at least to an altitude of 5,050 feet above sea level. It is in general considerably indurated. West of the mineralized area basalt flows are intercalated with the conglomerate.

The older pre-Cambrian granitic rocks already mentioned do not occur in the mineralized belts. The earliest intrusive rock in the district is olivine diabase, of unknown age, found as sills from a few feet to several hundred feet thick, intruding schist and the Apache group. The effect of the diabase on the invaded sediments is very slight other than hardening by baking. Where it invades Mescal limestone, tremolite and other silicate minerals, including forsterite, are locally developed. A common alteration product at the Mescal limestone contact is serpentine derived from olivine. The diabase is the host of many of the ore bodies of the district. It is undoubtedly much older than the ore but is younger than the beds of the Apache group. Recent work in central Arizona tends to show that the diabase is confined to the Apache group and that dikes cutting later sediments are to be assigned to a separate age.

The principal intrusive masses closely associated with the ore deposits are the Schultze granite (with its porphyritic phases) and the Lost Gulch monzonite (with the Willow Spring granite phase). Neither of these intrudes rocks younger than diabase, but from their similarity in composition to definitely post-Cretaceous intrusive stocks in the Dripping Spring Mountains, their age has been assumed to be late Mesozoic or Tertiary (20, pp. 59–67).

The Schultze granite is generally porphyritic. Fresh specimens are nearly white, weathering pale yellow. The constituents visible to the unaided eye are coarse white phenocrysts of orthoclase, in a medium-grained groundmass of quartz, oligoclase, and biotite (20, pp. 59–61). The mass forms an irregular stock intruding schist in the Pinal Mountains, south of the disseminated ore bodies of Miami. Its major axis trends about N. 50° E. Its total length is about 8 miles, and its average width about 2 miles, with a maximum, near the Schultze ranch, of 6 miles. It is covered at the northeast end by Gila conglomerate and at the southwest end by dacite. Erosion has truncated the stock somewhere between lower apical and medial. At the northwest end of the porphyritic lobe west of Miami the granite intrudes the schist, in part as a laccolith.

The only other extensive intrusive rock, the Lost Gulch monzonite, differs in composition from the typical Tertiary rocks of the region in having a higher lime and lower alumina content, so that Ransome is doubtful of its age. The field relations are also indefinite, as it crops out between pre-Cambrian granite a mile to the north and Schultze granite porphyry a mile to the south. It definitely cuts the Pinal schist and may possibly be older than the associated diabase. It is extensively mineralized by copper-bearing pyrite and is cut by veins carrying gold. It is bounded by post-dacite faults on all sides except its northeast end, where it is capped by Gila conglomerate. Like the separate smaller mass of Willow Spring granite, which it resembles, it trends parallel to the Schultze granite—that is, about N. 50° E. The total exposed length is a little more than 5 miles, and its average width is a little over a mile. The typical Lost Gulch monzonite is a fine-grained gray rock containing scattered crystals of potassium feldspar and smaller ones of plagioclase (20, pp. 51–52). Its fine grain, its general alinement with the Schultze granite, and its impregnation with pyrite and chalcopyrite indicate that its probable age is close to that of the Schultze granite.

Erosion remnants of extrusive dacite, younger than all other formations except the Gila conglomerate, crop out over the whole of the mineralized area. This extrusive rock is best preserved to the west, between Miami, Ray, and Superior, where it is several thousand feet thick. The largest exposure close to the mineral area occupies about 6 square miles north of Webster Gulch and south of Webster Mountain. The rock also crops out extensively on the southwest slopes of the Globe Hills, northwest of the Old Dominion mine, for a length of about 2 miles.

Structural history

During late Proterozoic time the old schist-granite complex was reduced to a peneplain and slowly sank during the deposition of the Apache group. The area was then probably uplifted. Extensive volcanism resulted in the intrusion of thick sills of diabase and the extrusion of basalt. Undoubtedly some faults now seen were begun at this time, but not enough detailed work has been done to differentiate these faults from others. No further deposition of sediments is known until upper Middle Cambrian time, when the area again sank and the Troy sandstone was deposited. At the end of Cambrian time the area was again raised above sea level and probably remained so during Ordovician, Silurian, and most of Devonian time, as no sediments of these ages exist in central Arizona. Possibly volcanism and faulting continued during this long period. During the Upper Devonian and Carboniferous sedimentation was uninterrupted, with only a possible minor break in lower Pennsylvanian time. During the late Carboniferous or early Mesozoic violent diastrophism, probably accompanied by faulting and possibly by igneous intrusion, occurred. The area was elevated and extensively eroded to a low level and was probably partly covered in connecting basins by Cretaceous sediments. Volcanic disturbances, probably with attendant faulting, accompanied and followed Cretaceous sedimentation. From the end of the Cretaceous to the present exact dating of diastrophic periods is impossible, owing to the absence of fossiliferous Tertiary sediments. All that is known is that extensive intrusion, undoubtedly accompanied by much faulting, occurred, followed by erosion and, later, by volcanic eruptions. After the volcanism, or possibly near its end, violent diastrophism gave birth to the present mountain chains and intermontane depressions. During this period many of the faults now seen were formed and the sediments were tilted. Finally, after long erosion, the whole of the mountain area and the Colorado Plateaus were again uplifted to their present altitudes. Extensive faulting accompanied this last diastrophism, much of it in the form of complicated overthrusting. Movement on many old faults was renewed. This period was followed by the present erosion cycle.

Owing to lack of detailed study, only broad generalizations can be made. When the diabases were intruded (probably during Proterozoic and possibly early Cambrian time) the sediments were probably essentially level. This is shown by the fact that the sills of diabase that intruded the underlying granite and schist are invariably parallel to the overlying beds. It is extremely unlikely that they would have been intruded at an angle, if the sediments had been tilted prior to intrusion. The great variability in the thickness of the sills and the nearly complete absence of contact-metamorphic effects point to much faulting of the Proterozoic beds to allow space for the sills. The direction and amount of this faulting have not yet been recognized. Considerable faulting is suggested by the variability in the thickness of both the top Mescal limestone (21) (Proterozoic) and the overlying Troy sandstone (Cambrian) (20, pp. 44–45). However, there was virtually no tilting, as shown by the almost exactly concordant attitude of the Proterozoic and Cambrian beds.

Similar uplift probably took place during Ordovician, Silurian, and early Devonian time, although little irregularity has been observed at the boundary of the Troy and the apparently conformably overlying Upper Devonian Martin limestone.

Owing to the almost complete erosion of the Cretaceous sediments and effusives from the central part of the mountain area and the lack of detailed work in the small areas where they are exposed, little is known of the late Carboniferous or early Mesozoic diastrophic period. In general, little tilting occurred, as the attitude of the Cretaceous and underlying Paleozoic sediments is virtually the same. The Cretaceous beds, however, rest on rocks of all previous ages from pre-Cambrian to Carboniferous, thus pointing to probable extensive faulting. Possibly the earliest post-Paleozoic intrusions, such as that of the Lost Gulch monzonite, took place during this period. In the southern part of the mountain area, at Bisbee, one large fault of this age strikes west to west-northwest. The strike of the Lost Gulch monzonite in the Miami area is east-northeast.

On the assumption that the intrusion of the Schultze granite and the mineralization of Globe and Miami were closely associated with the late Mesozoic or early Tertiary (Laramide) diastrophism, the direction of major faulting during this period was east-northeast. Further evidence of the direction of shearing is seen in the major direction of jointing in the Schultze granite, which is N. 65° E. (22, p. 67). At Superior, Miami, and Globe the subsequent oxidation of the ore deposits points to little if any tilting of the ground during this period. This is especially well shown at Superior, where the old ground-water level at the bottom of the oxidized zone is now inclined parallel to the bedding of the sediments of the wall rocks.

The intense diastrophism that followed a long period of erosion and was followed in turn by extensive volcanism probably first established the present northwest alinement of mountain ranges and bordering basins. The forces were compressive, and monoclinal folds were formed, the crests being the present mountain chains and the troughs the present intermontane plains. Flexure was almost completely lacking; the rocks involved, especially in the steep flanks of the monoclines, were shattered into an intricate mosaic of fault blocks. Probably all previous faults were reopened and subjected to renewed movement. Subsequent erosion wore down the ridges and deposited the detritus in the isolated internally draining basins. This detrital material consolidated into the Gila conglomerate. The long intermontane plain, the constricted northwest end of which now separates the Pinal Mountains and the Globe Hills, then extended over most of the northeast end of the Pinal Mountains and probably connected with the Tonto Creek Basin northeast of the Mazatzal Mountains.

The last diastrophism, probably in early Quaternary time, not only raised the mountain and plateau provinces as wholes but also renewed differential movements between individual mountain ranges and bordering plains. In the Globe-Miami area this renewal of movement buckled the old low area between the Pinal Mountains and Globe Hills into a high area by encroachment of the Pinal Mountains northeastward. The faulting at this time was both normal and overthrust and along diverse trends. Many of the older faults were reopened, and many new ones were developed. The present erosion cycle has nearly stripped the Gila conglomerate cover and has exposed in the Miami end of the district the old pre-Gila and pre-dacite complex.

Ore deposits

Three types of ore deposits are found in the district—fault veins, disseminated sulphide deposits, and exotic deposits derived from others through the agency of ground waters. The fault veins occur almost exclusively in the Globe end of the district. A few small veins are also found in the central Pinal Mountains south of the Schultze granite, and other small veins are found at the northwest end of the Miami end of the district. The other two types of deposits are found exclusively in the Miami end of the district.

Vein deposits

The most productive veins of the district are in the Globe Hills northeast of the town of Globe. The ore has chiefly replaced the wall rocks close to fault fissures and shear zones striking about N. 50° E. and dipping both northwest and southeast. The deposits form irregularly spaced shoots and bodies commonly connected by narrower ore bodies following the fissures.

The Globe Hills are cut by a series of closely parallel northeast faults over a width of about 4 miles. In most of this area the faults cut diabase and sediments of the Apache group, but at the southwest end they cut Paleozoic limestones, and the whole zone is finally limited on the southwest by dacite and Gila conglomerate. Most of the movement on the northeast faults antedates the dacite, although some post-dacite and post-Gila conglomerate movement has taken place on some of them (22, p. 139). The northeastward-trending wedges have been extensively cut by later north-south to north-northwest faults, which have in general stepped down the blocks to the west, thus exposing progressively younger sediments toward the southwestern flanks of the hills. The dip of the sediments is variable but in general is to the south at angles averaging not over 15°. The northeast fault zone is almost exactly in trend with the long axis of the Schultze granite. Porphyry intrusions, however, are rare in the Globe Hills, although a few small dikes, closely resembling the Schultze granite, have been encountered in the Old Dominion mine.

The center of mineralization is near the center of the northeast fault zone, and most of the ore has come from bodies closely associated with the large Old Dominion fault. This fault can be followed on the surface, with numerous interruptions by later north-south faults, for about 8,000 feet, but at its northeast end it splits or "horsetails" into several closely spaced parallel faults, which are best exposed at Copper Hill, 2 miles northeast of Globe. The zone is finally cut off by the Budget fault, a large northwestward-trending dislocation, beyond which it has not been definitely recognized. The largest production from this fault vein has come from its southwest end, in the Old Dominion-United Globe mine, but considerable ore has come from its northeast end, in the Arizona Commercial, Iron Cap, and Boston & Superior mines. The fault strikes about N. 50° E. and dips 45°–80° SE. It is normal, with pre-dacite movement of over 1,0C0 feet and post-dacite movement of about 100 feet. At its southwest end the fault cuts dacite, but for most of its length it has diabase on the footwall and Paleozoic limestone on the hanging wall. It was here that the rich outcrops of oxidized ore were found. The vein is cut off at its southwest end by a post-Gila northwest fault, which underground exploration has shown to be a series of step faults with a total throw of several thousand feet down to the southwest. In the upper levels of the mine the oxidized ore and overlying gossan were stoped up to the dacite covering, which was fresh and unoxidized, showing that mineralization and most of the oxidation and enrichment of the ore took place before the dacite eruption.

In the upper levels of the Old Dominion mine the ore occurred predominantly as irregular metasomatic replacement deposits in limestone in the hanging wall of the fault. Replacement extended as far as 300 feet away from the fault. The footwall of the fault was here chiefly diabase, intruded at the general horizon of the Mescal limestone. All of this ore was thoroughly oxidized and consisted of kaolinized masses veined and impregnated with chrysocolla, cuprite, malachite, and abundant greasy specularite and limonite. Oxidation extended about to the 900-foot level in the main part of the mine but much deeper at the southwest end, southwest of the northwestward-trending fault zone. Below the Paleozoic limestone the ore bodies in quartzite, Mescal limestone, and intrusive diabase were confined to an area much closer to the fault, and the footwall changed from diabase to quartzite. The oxidized ore merged into chalcocite ore replacing pyrite, which in turn graded downward into pyrite and chalcopyrite with chalcocite films and finally into primary pyrite and chalcopyrite. In the lower levels, below the oxidized replacement deposits in limestone, the ore bodies ranged from 5 to 80 feet in thickness and the ore gradually faded out into the walls. The wall rocks are little altered other than by the addition of sulphides. Some chloritization and carbonation have occurred, but almost no silicification or sericitization.

The Old Dominion mine has been developed to a depth of over 2,500 feet, and in the lowest levels the Old Dominion fault, especially at the southwest end of the mine, becomes a wide ill-defined shear zone along which were large ore bodies replacing diabase or quartzite.

In the mines at the northeast end of the Old Dominion fault zone all the ore bodies are like those on the lower level of the Old Dominion. Oxidation here was shallow, and most of the ore occurred as replacement shoots of enriched and primary ore in diabase and quartzite. In the Arizona Commercial mine the footwall in the lower levels is Pinal schist.

Several other northeast faults in the Globe Hills, more notably the Buckeye, Buffalo, and Mallory faults, carried ore deposits similar to those of the Old Dominion fault, but production from them has been insignificant.

The only other largely productive veins in the district have been the Summit vein in the Pinal Mountains, a replacement vein in schist south of the outcrop of the Schultze granite, and the Continental vein at the head of Webster Gulch, 4 miles northwest of Miami, a vein cutting diabase, quartzite, and limestone at their contact with pre-Cambrian granite.

Disseminated-sulphide deposits

Disseminated-sulphide deposits, although developed comparatively recently and of much lower copper tenor, have yielded over 70 percent of the district's output. They are all in the west end of the district, northwest of the town of Miami. The structure of this end of the district is of great interest, as this is one of the few places in the mountain area where the structure of the tectonic depressions may be studied. This pre-Gila lowland, owing to post-Gila buckling, is now well exposed and is hidden only in a few places by uneroded Gila conglomerate and dacite. Not enough detailed work has been done to solve the structural problems. In general, the Gila conglomerate was deposited on an extremely shattered complex involving all older rocks including the dacite. A significant feature is the prevalence of complicated low-angle overthrust faults involving the dacite, Schultze granite, and Pinal schist (20, pp. 116–120).

Pre-dacite erosion had largely stripped the Proterozoic and Paleozoic sediments from the mineralized part of the area. To the north a former northeastward-trending trough of Paleozoic outcrops from the Continental mine to Sleeping Beauty Peak is suggested. At the west end of this possible pre-dacite trough are the only outcrops of the Whitetail conglomerate. Post-dacite northwest faulting combined with renewed movement on the older northeastward-trending faults has cut the whole area into an extremely complicated patchwork of small fault blocks. Renewal of movement on all previous faults and the development of new faults at the time of the post-Gila buckling have still further complicated the structural problem. The most prominent of these later faults is the Miami fault, at the east end of the district, which strikes northeast. It is a normal fault, which has dropped the Gila conglomerate on its southeast side over 1,000 feet. The area was invaded in pre-dacite time by a large granitic intrusion, the largest outcrop of which is in the Pinal Mountains south of the mineralized area. In the mineralized district proper a porphyritic phase of this Schultze granite invaded the Pinal schist as irregular sills. Mineralized solutions affected both the schist and the porphyry but not the dacite or the Gila conglomerate. Subsequent oxidation resulting in the enrichment of the originally lean protore into commercial ore deposits took place before the diastrophism which produced the northwestern alinement of mountains and valleys, as no faults of this period are definitely pre-ore, and all those which have been recognized have post-ore movement. The strike of the ore zone is east-northeast and probably was governed by faulting along this trend. Several large faults striking east-northeast, showing later reopening, crop out north of the mineralized area. One of the most conspicuous of these is that in the workings of the Black Warrior and Black Copper mines, which was reopened after the pouring out of the dacite.

The ore deposits consist of blanket deposits of disseminated chalcocite or of oxidized copper minerals or mixtures of these in both schist and porphyry close to the porphyry contact. The horizontal projection of the ore zone forms a bow, convex to the north, whose west end strikes east-northeast and whose east end strikes nearly due east. The length of the bow from the western extremity of Inspiration ground to the point where it is terminated on the east by the post-Gila Miami fault is about 18,500 feet. In this arc the width of ore ranges from 300 to 2,700 feet and averages about 700 feet. The thickness of the blankets depends on the limiting grade in depth. In the past the thickness has varied from 100 to 500 feet and has averaged between 200 and 300 feet. Most of the ore mined has been chalcocite ore, but large bodies of oxidized ore and mixed "oxides" and "sulphides" have been mined in recent years and remain in the reserves. All ore except the oxidized ore exposed by erosion is covered by a reddish-brown oxidized capping of schist or porphyry. For most of the length of the ore body the chalcocite ore is capped by oxidized ore. In the center of the length of the ore body, where post-ore faulting has dislocated it, the ore on the footwall side is all oxidized and rests on protore with only a very thin chalcocite zone intervening.

The different zones are in no way related to the present ground-water table, as chalcocite and oxidized ore are found 1,000 feet below the present water level at the west end of the ore body, and in the center of the bow chalcocite ore is found 400 feet above the water level. The drill-hole records at the west end of the deposit show that the pre-dacite surface roughly parallels the dip of the ore. Probably the enrichment and oxidation took place during the long pre-dacite erosion period, in which the covering of Proterozoic and Paleozoic sediments was stripped. Subsequent deformation, which has exposed parts of the enriched chalcocite ore to oxidation, has probably caused some of the large zones of mixed oxides and sulphides in the ore body.

The porphyry and schist were thoroughly shattered, and mineral solutions permeated the ore zone through minute, closely spaced fractures and deposited the sulphides together with silica in a very irregular network of veinlets. The predominant sulphide deposited was pyrite, with very subordinate chalcopyrite and molybdenite. The feldspars of the porphyry were attacked and partly sericitized by the solutions. A little sulphide penetrated the walls between fractures, but most of it is confined to the fractures. Subsequent oxidation produced a capping of schist or porphyry stained reddish brown and containing a minute network of limonite and silica veinlets, underlain at and below the original water table by a blanket of ore composed of the same network of veinlets containing pyrite wholly or partly replaced by chalcocite. This in turn graded down into the original protore. The "oxide" and mixed ores were probably developed after later periods of diastrophism, when the original chalcocite zone was raised into the zone of oxidation. Here it was attacked by ground waters charged with overwhelming amounts of oxygen, which prevented the solution of the chalcocite and precipitated the copper in place as silicates, carbonates, and oxides.

In addition to the main ore zone just described two others of lower grade exist in the district. One of these is within the Schultze granite about 3 miles southwest of the end of the main ore body. In this zone fracturing was not nearly as intense as in the main ore zone. Considerable ore has been developed by drilling and underground exploration. A second large low-grade ore body partly explored by drilling is 3 miles north of the main ore zone in the Lost Gulch monzonite. In this deposit fracturing was also less intense than in the main ore zone, and the solutions were more siliceous, resulting in a mass more impervious to ground waters. Chalcocitization was less perfect and more erratic.

A third still prospective ore body is east of the Miami fault under a cover of over 1,000 feet of Gila conglomerate. The ore consists of chrysocolla, melaconite, malachite, azurite, limonite, and manganese oxide in a shear zone in Pinal schist. Exploration has so far failed to find sulphides below the oxidized ore, and the ore body may be exotic.

Exotic deposits

The only other types of ore body found in the district are those formed by the action of cold ground waters carrying copper salts leached from sulphide-ore outcrops. One of these exotic ore bodies is at the Black Warrior and Black Copper mines, north of Miami. The ore is composed of chrysocolla, manganese oxide, and black copper oxide, replacing dacite tuff in a northeastward-striking fracture zone. The dacite covers schist, which the ore does not penetrate. No sulphides are found below the oxidized ore, and the thickness of the ore is not great. It was undoubtedly derived from the leaching of a chalcocite zone exposed by post-dacite faulting, and the replacement of the soft tuff by the run-off waters highly charged with copper sulphates, sulphuric acid, and silica. The ore was localized by a northeastward-striking fault, which either was followed by the copper-charged waters or dammed the water from other streams. These ore bodies have been fairly productive and were the first to be developed in the Miami end of the district.

Summary

The ore deposits from the Globe and Miami ends of the district, though differing markedly from each other, have also some very significant similarities. Both were formed in post-Paleozoic, pre-dacite time, and both were closely governed by east-northeast structure. Both are in or close to the margin of the principal intrusive stock. The change from a typical vein deposit into large irregularly spaced flat ore bodies in the lower levels of the Old Dominion mine close to the schist contact suggests the possibility that the Miami ore zone may have been the root of a series of vein deposits similar to those at the Globe end of the district, which were removed by erosion prior to the outflow of the dacite.

Ray-Christmas district [4]

History and production

The copper deposits at Ray and Christmas were discovered in the early seventies. However, they were relatively inaccessible and slow to be exploited. The first locations were made in 1879 or 1880 at Ray. The Pinal Copper Co. was organized in 1881 to mine and smelt the native copper ore of one of the outcrops. A small furnace produced a little black copper from carefully cobbed ore, said to have run between 50 and 60 percent of copper. This company continued to develop at Ray, and in 1883 its name was changed to the Ray Copper Co. A small furnace was built on the Gila River, and a substantial tonnage of sulphide ore of 7 to 15 percent grade was developed. All work ceased after the break in copper prices at the end of 1883.

The deposits on London and Christmas Mountains, southeast of Ray, were discovered about the same time as those at Ray. The Christmas deposits were acquired in 1883 by Dr. James Douglas, of Phelps, Dodge & Co. The San Carlos Copper Co. was organized, and a small blast furnace was built in 1884, which made a short run. The property was closed shortly afterward, as a careful survey showed it to be just within the San Carlos Indian Reservation and therefore not subject to mineral location.

After the abandonment of the Ray deposit in 1884 the district was virtually idle for 14 years, when in 1898 the old Ray Copper Co. claims were purchased by a British syndicate organized as the Ray Copper Mines Co. The old work was continued, and considerable capital was invested in the construction of a 43-mile wagon road down the Gila River and across the desert to the nearest railroad point, at Red Rock. A 250-ton concentrator, shops, and smelter were built at Kelvin, on the Gila River, and a 5-mile narrow-gage railroad line was built from the mine to Kelvin. A small production was made of concentrates, which were hauled to Red Rock, but the venture did not prove a commercial success, and the property was closed in 1901.

In 1902 that part of the Indian reservation containing the Christmas deposits and nearby coal beds was thrown open for location. The San Carlos Copper Co. was revived as the Saddle Mountain Mining Co., which also acquired the principal coal locations. The importance of the district was realized, and in 1905 a railroad was built from Phoenix through Florence and up the Gila River to Winkelman, and in 1909 this line was extended to Christmas. The railroad revived interest in the district. At Ray the holdings of the Ray Copper Mines Co. were purchased by D. C. Jackling and associates, of Bingham, Utah, and

[4] The description of the Ray district is largely a condensation of a paper by Ransome (20) with slight additions. The account of the Christmas district closely follows an excellent description by Ross (24, pp. 52–60).

two other groups were purchased by other interests. Churn-drill development by all three companies proved the existence of a large low-grade disseminated copper deposit. The three companies were finally merged in 1910 as the Ray Consolidated Copper Co., under the control of Mr. Jackling. The American Smelting & Refining Co. constructed a smelter at Hayden, 14 miles southeast of Kelvin, near the junction of the Gila and San Pedro Rivers. The Ray Consolidated at the same time began to develop and equip the property for production on a large scale. This work included the driving of about 30 miles of shafts, drifts, and raises, the building of a broad-gage railroad from Ray to Kelvin, and the construction at the smelter site of an 8,000-ton concentrator. Work was completed early in 1912, at a cost of over $10,000,000. The property was operated by the Ray Consolidated until 1926, when it was merged, with the Chino Copper Co. of New Mexico and the Nevada Consolidated Copper Co. of Nevada, into the Nevada Consolidated Copper Co. During this time improvements in milling, expecially developments of the flotation process, and great improvements in mining methods permitted expansion of the economic boundary of the ore body to include a large tonnage of low-grade material in the ore reserves. The potential life of the mine has thereby been extended many years beyond that originally anticipated. The property is now idle pending better market conditions.

The Christmas deposits were operated after the completion of the railroad by the Saddle Mountain Mining Co. until 1909, when they were sold to the Development Co. of America, the promoter of a large group of mines in Arizona. The mine was operated by the subsidiary Gila Copper Sulphide Co. until the collapse of the parent company in 1912. During the high copper market of the World War operations were resumed on lease account by the American Smelting & Refining Co. They were discontinued in 1918. In 1926 the property finally passed under the control of the Iron Cap Copper Co., of Globe, which, on the exhaustion of its Globe mine, operated the Christmas mine under the name "Christmas Copper Co." The property was thoroughly reequipped, a 400-ton concentrator and a large power plant were built, and production was well under way by 1929. The mine is now idle awaiting a more auspicious market.

Metal production of Ray-Christmas district

Period	Copper (pounds)	Silver (ounces)	Gold (ounces)	Total value
Ray:				
1881	300,000	...	...	$54,600
1900	480,000	...	...	80,160
1907–29	1,077,457,913	342,070	12,987	[a] 190,274,762
	1,078,237,913	342,070	12,987	190,409,522
Christmas:				
1905–7	4,500,000	...	...	823,500
1902–29 [b]	38,469,217	220,627	11,427	[c] 8,387,230
	42,969,217	220,627	11,427	9,210,730
Grand total	1,121,207,130	562,697	24,414	199,620,252

[a] Including a little lead. [b] Christmas-London. [c] Including some lead and zinc.

Topography

The Ray-Christmas district is in the mountain area of Arizona, 20 to 25 miles south-southeast of Globe. Ray is about 16 miles northwest of Christmas. The Ray end of the district is at the northwest end of the San Pedro River intermontane plain, which extends from the Mexican border without interruption for 120 miles. In the Ray-Christmas area the plain is drained by the Gila River, which flows northwestward from Winkelman to Kelvin, a distance of 14 miles. The northwestern 5 miles beyond Kelvin is drained by Mineral Creek, which flows south into the Gila at Kelvin. In this distance the plain averages about 5 miles in width and gradually narrows to a wedge point at Ray. The plain is here bounded on the northeast by the Dripping Spring Mountains, a northwestward-trending ridge with an average width of about 2 miles. This range starts at the Gila River at Christmas and extends 20 miles to the northwest, where it gradually merges with the high dacite-covered plateau north of Ray. The plain is bounded on the southwest by the Tortilla Mountains, a wide, much dissected granite massif through which the Gila River has cut its gorge between Kelvin and Florence. The Christmas end of the district is at the southeast end of the Dripping Spring Mountains. The intermontane plain is about 1,900 feet above sea level at Kelvin and 2,000 feet at Ray. The Dripping Spring Range reaches a maximum altitude of over 5,000 feet at Troy and Tam O'Shanter Mountains, and Christmas is about 2,600 feet above sea level, or 600 feet above the Gila River.

The district is served by the Arizona Eastern branch of the Southern Pacific Railroad, which joins the main line near Phoenix and runs up the valley of the Gila River from Florence to Christmas. Ray is connected to this line by a 5-mile railroad owned and operated by the Nevada Consolidated Copper Co. The district is connected by surface highways with Tucson, Globe, Phoenix, and Superior.

Rocks of the district

The geology of the district is shown on plates 9 and 10. The pre-Cambrian rocks and the Proterozoic, Paleozoic, and Tertiary sediments are much like those of the Globe-Miami district. Upper Cretaceous extrusive andesites and pyroclastic rocks intercalated with sediments occur at the south end of the Dripping Spring Mountains, near Christmas. The intrusive rocks are definitely later than these lavas (23, pp. 25–28).

Near Ray the Pinal schist crops out in the hills west of Mineral Creek. It is intruded by small diabase sills, and the whole is extensively intruded by stocks and dikes of porphyry. East of Mineral Creek the Dripping Spring Mountains expose an irregular patchwork of Proterozoic and Paleozoic sediments, the former extensively intruded by diabase. At Christmas the principal outcrops are of Cretaceous volcanic rocks and Carboniferous limestone intruded by stocks and dikes of diorite porphyry.

The oldest intrusive is diabase, which forms sills in the schist and Proterozoic sediments. It is identical in all respects with that of the Globe-Miami district.

Near Ray the largest post-Paleozoic intrusive mass seen is the irregular stock of Granite Mountain quartz monzonite porphyry, which intrudes Pinal schist and diabase. Its longest dimension, about 2 miles, lies east and west, and its maximum width, at its west end, is over half a mile. Smaller stocks and dikes of the same porphyry cut the schist north of the main mass, and others cut Proterozoic and Paleozoic sediments in the Dripping Spring Mountains east of Ray. The rock closely resembles some of the Schultze granite of Miami (20, p. 62).

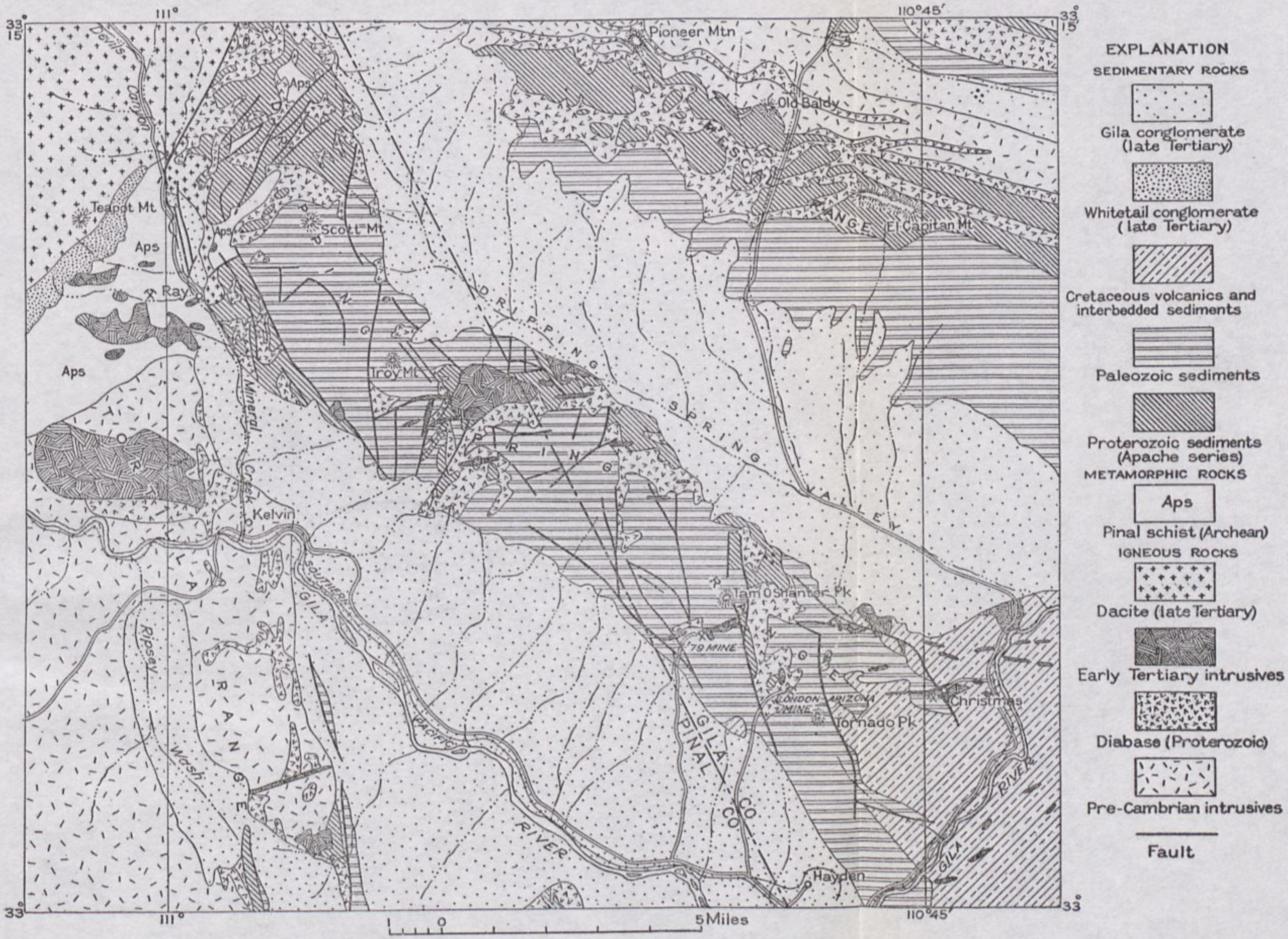
A similar monzonite porphyry, but darker gray and containing more abundant pink orthoclase, crops out at Teapot Mountain, northwest of Ray.

A third intrusive rock, which occurs south of Ray and as a small stock intruding the Cretaceous series at Christmas, is quartz diorite porphyry (20, p. 65)

Structure

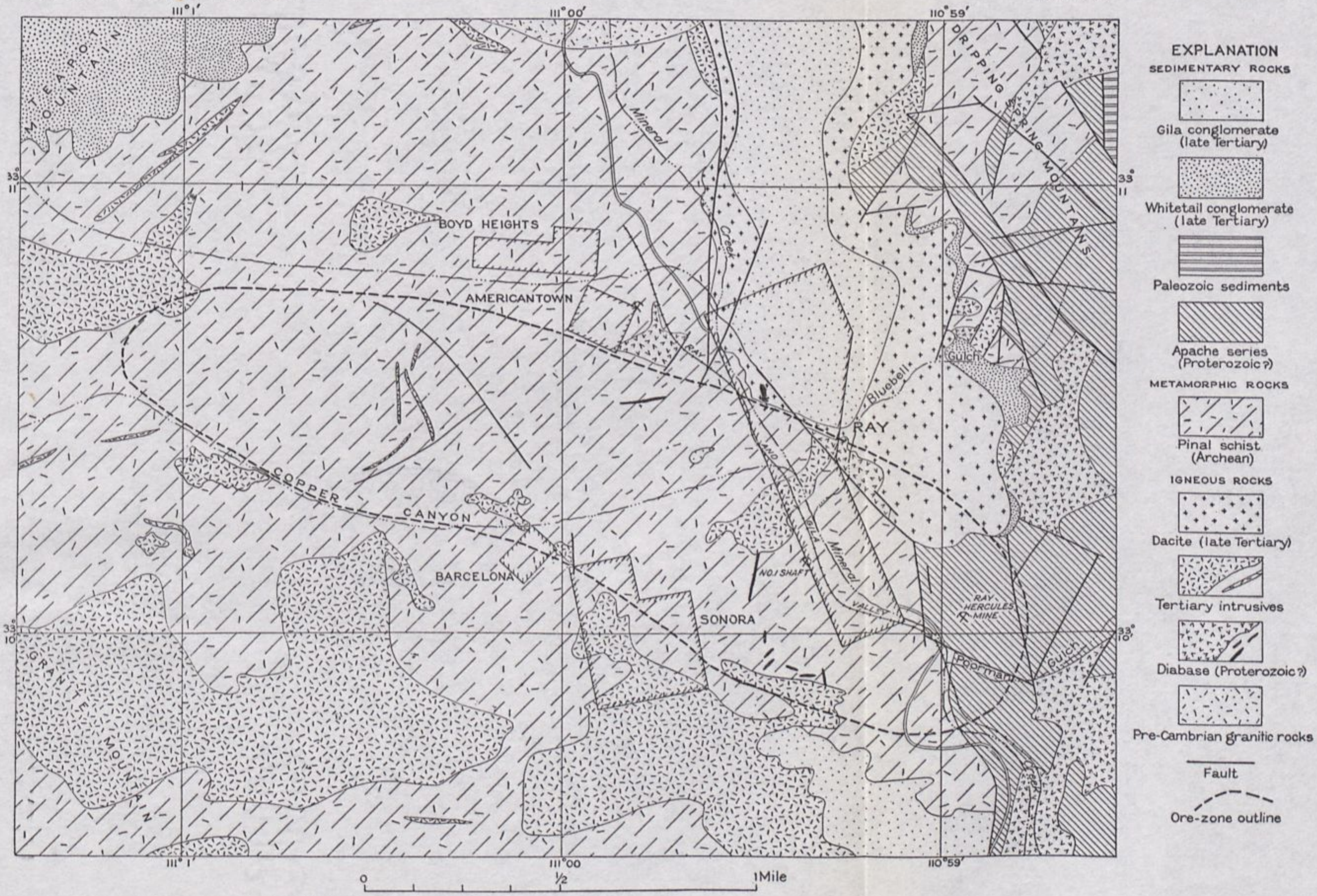
The structure in the Ray-Christmas district is complicated by the same factors as in the Globe-Miami district. The area near Ray resembles that near Miami in that the pre-dacite rocks now crop out because of post-Gila buckling of part of an older pre-Gila, post-dacite depression. Most of this older low area southeast of Ray is now followed by Mineral Creek, the Gila River, and the San Pedro River. The old lowland extended at least 3 miles northwest of Ray, as shown by Gila conglomerate outcrops east of Mineral Creek. The bordering high mountain area to the northeast has been far more minutely shattered into fault blocks than any of the ranges in the Globe-Miami region. The pre-dacite structural trend is apparent in the relatively unfaulted area west and southwest of Ray, where the Granite Mountain porphyry mass and the associated ore body both run east-west. At Christmas the quartz diorite stock directly associated with the ore also trends east-west.

How much of the intense shattering in the Dripping Spring Mountains antedates the dacite eruptions is uncertain. The Whitetail conglomerate, which crops out on the mountain flanks east of Ray, is not involved in all the dislocations of the underlying rocks, and the pre-dacite faults appear to have no definite trend, as they have in the Globe Hills. The structure is complicated by the numerous porphyry dikes. In general the youngest faults, especially those close to the borders of the range, some of which involve the Gila conglomerate, strike northwest. Near Christmas most of the monzonite and diorite porphyry dikes and small stocks trend east-west. Many of the smaller dikes, however, followed northward-trending faults. At Troy Basin, in the center of the range, a large monzonite porphyry stock, closely allied in composition to the Granite Mountain porphyry of Ray, also trends east-west. Many smaller dikes crop out between Ray and Troy Basin. One is associated with lead-silver ore mined by the Ray Silver Lead Co. Between Troy Basin and London Hill a small stock of monzonite porphyry cuts Carboniferous limestone and is closely associated with lead-silver and copper-silver ore at the Seventy Nine mine. The dikes and stock trend about N. 60° E. It would thus appear that the prevailing pre-dacite structure was east-west to northeast, with minor north-south cross structure. Near Ray the north-south cross faults are subordinate in guiding the numerous



GEOLOGIC MAP OF THE RAY-CHRISTMAS AREA, ARIZONA

After F. L. Ransome and C. P. Ross.



GEOLOGIC MAP OF THE RAY DISTRICT, ARIZONA

After F. L. Ransome.

small dikes in the ore body. It thus appears that the post-Cretaceous early diastrophism in the district, with which the porphyry intrusions and ore deposition were associated, developed east-west to east-northeast structure with minor north-south cross faulting, like that in the Globe-Miami district, and that the northwest alinement of mountains and plains was post-dacite, as at Globe and Miami. Probably the intense shattering in the northwest belt occupied by the Dripping Spring Mountains occurred during post-dacite time, when new northwest faults were developed and movement on the older faults was renewed.

Near Ray the dislocation of the pre-dacite Whitetail conglomerate between its outcrop east of Mineral Creek and its outcrop 3 miles west of Ray is not over 500 feet. The Gila conglomerate is also involved in the dislocation. A mile north of Ray post-Gila faulting east of Mineral Creek has raised the block between Mineral Creek and Teapot Mountain about 1,000 feet. The post-Gila buckling that led to the erosion of the conglomerate and underlying dacite from the ore outcrop was apparently hinged near Ray and had its major movement to the north. Recent erosion has exposed virtually all of the old pre-dacite surface. The progressive thickening of the Whitetail conglomerate from south to north suggests that during the deposition of the dacite there was a hill or ridge where the ore body now crops out, with a low basin on the north and northwest.

Ore bodies

Ray

The Ray ore body is very similar to the Miami-Inspiration ore body. It is a large blanketlike deposit replacing Pinal schist, porphyry, and diabase. Most of the ore occurs in the schist. In the east end of the ore body, in ground formerly owned by the Ray Hercules Co. east of Mineral Creek, post-Gila faulting has dropped the ore blanket about 500 feet. In this end of the ore body porphyry and diabase are the principal host rocks. The blanket is about 13,000 feet long from east to west, and the width averages about 2,500 feet and ranges from 1,000 to 3,500 feet. The thickness of the blanket as mined ranges from 50 to 400 feet and averages about 150 feet. The ore body lies close to the northern margin of the Granite Mountain porphyry stock. Postmineral faulting is slight except at its east end. The present cycle of erosion has modified the pre-dacite surface to only a minor extent. Post-ore diastrophism has apparently dislocated the ore-body block without material tilting or faulting.

At Ray the premineral shattering was not as intense as at Miami, and the resulting sulphide veinlets were larger and less intricate in pattern. The diabase sills at Ray affected enrichment considerably. The sills commonly acted as comparatively impervious barriers, resulting in rich ore lenses at their upper contacts, and prevented efficient enrichment below. This is most marked at the down-faulted east end of the ore body and in the adjoining ground west of Mineral Creek. The oxidized zone above the enriched ore is like that at Miami and averages about 250 feet in thickness. At Ray, however, the only oxidized ores that crop out are those associated with outcropping protective diabase sills. The absence of post-ore tilting and faulting has prevented the oxidation in place of former chalcocite ore, as at Miami. The position of the top of the chalcocite blanket at Ray relative to the present ground-water level is not known exactly. It is slightly below the water level of the Gila River at Kelvin. Probably little enrichment has taken place in the present erosion cycle, and, as at Miami, the major enrichment was effected during the pre-dacite erosion period, which stripped the overlying sediments and exposed virtually the present surface of schist, diabase, and porphyry.

Christmas

The Christmas-London Hill area, at the southeast end of the Dripping Spring Mountains, is in the Banner mining district.

The ore deposits at Christmas are quite different from those at Ray. They are contact-metamorphic deposits replacing Carboniferous limestone near its contact with quartz diorite porphyry. The primary ore of the mine consists of pyrite and chalcopyrite associated with garnet, diopside, magnetite, and very subordinate quartz. Oxidation has changed it directly to oxidized ore without the intermediate enriched sulphide stage. The primary ore is sufficiently high in copper content to constitute commercial ore when the copper market is normal, and the reserves consist almost entirely of this material.

The ore bodies are associated intimately with an elongated stock of quartz diorite porphyry which strikes east and dips steeply south. Its total length is 8,500 feet and its maximum width about 1,500 feet. The stock invades both Carboniferous limestone and Cretaceous volcanic rocks. The ore bodies have replaced Carboniferous limestone close to or at the actual contact. The principal workings form a halo around the western margin of the stock for a total length of about 3,000 feet. Both the north and south limbs of the halo extend to a large postmineral fault that strikes about N. 45° W., with a throw of at least 1,000 feet down to the northeast. The hanging wall has been only partly explored. The stock itself is little altered, except by scattered veinlets of pyrite. The east and west ends of the porphyry intrude Cretaceous volcanic rocks, which show almost no alteration other than induration at the contacts.

The Carboniferous limestone is composed of a succession of pure limestone interbedded with relatively more impure shaly and cherty members. The ore has replaced the purer limestone beds, leaving the relatively impervious shaly beds untouched. Close to the contact the replacement deposits consist mainly of garnet and magnetite, which within a few feet give way to disseminated pyrite and chalcopyrite in a gangue of sugary calcite containing irregular bands of garnet and diopside. This ore zone extends 100 to 300 feet from the contact and ends sharply against a zone of marble of variable width, commonly containing veinlets of pure chalcopyrite or bornite. The marble in turn grades insensibly into unaltered limestone. The ore beds range from 6 to 20 feet in thickness and are separated by shale beds from a few inches to several feet thick. The limestone dips about 15° SE. The mineralization varied in intensity, resulting in considerable irregularity in the replacement of individual beds. The total vertical thickness of limestone subject to partial replacement is at least 1,000 feet, with the bottom not yet reached by exploratory work. The deposits are typical contact-metamorphic deposits but are noteworthy for the paucity of silica and for the unusual thickness of replaceable beds.

The Magma mine, Superior

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Location, history, and production

The Magma copper mine is at Superior, about 65 miles east of Phoenix and 22 miles west of Miami. The region is one of mountain ranges whose general trend is approximately north. Between the ranges lie more or less level valleys filled with detritus. The Magma mine lies near the western foot of one of these ranges, locally known as Apache Leap, a spur of the Pinal Mountains. The mine workings, whose general trend is east, extend under the valley floor to the west and penetrate deeply into the mountain range on the east.

The region around the mine, like all other mountainous localities of southern Arizona, is semiarid. Streams flow intermittently and only during the rainy season. The average annual rainfall is about 17 inches, mostly falling in the early spring and late summer. The altitude of the town of Superior is 2,700 feet, and that of the collar of the main working shaft 3,400 feet.

The Magma ore body was located late in the decade 1870–80, during the activity that followed the location and development of the Silver King mine, 2 miles to the north. A vertical shaft, the Silver Queen, was sunk to the 400 level, and a few pockets of silver-enriched chalcocite were discovered. These were soon worked out, and activity was suspended. The property was worked intermittently until 1909, when it was acquired by the present owners.

The company began shipments in a small way early in its operations, hauling sorted ore by teams to Florence, 30 miles away on the Arizona Eastern Railroad. In 1914 a narrow-gage railroad was completed to the mine at the same time that a concentrator was started. Shipments were continuous until 1921, when they were temporarily discontinued during the construction of the company's smelter. The smelter was blown in in 1923, and shipments have been continuous to date but at a reduced rate for the last 3 years owing to the low price of copper.

To January 1, 1932, the mine has produced about 311,000,000 pounds of recoverable copper from 2,605,000 tons of ore. The ore also contained about 4 ounces of silver and 0.04 ounce of gold to the ton.

Net smelter production of Magma mine, 1923–31

Year	Ore (tons)	Copper (pounds)	Silver (ounces)	Gold (ounces)
1923	78,889	6,956,576	204,081	2,567
1924	222,307	23,301,511	533,204	7,589
1925	229,377	27,020,516	719,881	9,085
1926	248,787	29,135,132	860,184	9,100
1927	221,855	28,502,521	989,652	8,528
1928	263,094	35,228,810	917,048	8,665
1929	269,579	36,516,511	1,031,535	10,196
1930	251,872	31,558,508	830,009	8,519
1931	231,862	28,760,628	701,576	7,513
	2,017,622	246,980,713	6,787,170	71,762

Geologic formations

The lowest geologic formation of the district is the Pinal schist, of pre-Cambrian age. Overlying the schist in ascending order are the Scanlan conglomerate, 15 feet thick; the Pioneer shale, 150 feet; the Barnes conglomerate, 15 to 20 feet; the Dripping Spring (lower) quartzite, 450 feet; and the Mescal limestone, 200 feet thick. None of these formations contain fossils. Overlying the Mescal limestone and separated from it by an erosional disconformity of slight relief is the Troy (upper) quartzite, 400 feet thick. This is unfossiliferous at Superior, but Cambrian fossils have been recently discovered in this formation in the Mescal Mountains, about 20 miles to the southeast. Overlying the Troy quartzite with no apparent unconformity are the Martin limestone, 340 feet thick, of Devonian age; the Escabrosa limestone, about 160 feet thick, of Mississippian age; and the Naco limestone, over 900 feet thick, of Pennsylvanian age. All these formations are exposed in the mine workings except the Pinal schist, the Scanlan conglomerate, and the Mescal limestone.

Overlying the Carboniferous limestone and filling in an old erosion surface on this formation is an extensive flow of Tertiary dacite, at least 800 feet thick at its western margin. This forms the summit of the range and is known locally as Apache Leap.

Intrusive into these formations are at least two closely conformable sills of diabase, whose total thickness near the Magma mine is over 2,500 feet. The upper sill intrudes the upper part of the upper (Troy) quartzite, and the lower part of this formation is missing. This sill is over 2,000 feet thick in the western part of the mine. At the bottom of this sill the Dripping Spring quartzite was encountered, and nearly the full thickness of this formation and that of the underlying Pioneer shale are exposed in the mine workings. At the horizon where the Scanlan conglomerate was expected a lower sill of diabase was encountered, which persists to the lowest workings of the mine (3,200-foot level).

The age of the diabase is uncertain. Ransome regards it as post-Carboniferous and pre-Tertiary; Darton, as pre-Cambrian. In the Magma mine the diabase does not come into contact with formations younger than the Troy quartzite.

In the main mine workings all the formations appear conformable. They strike nearly north and dip about 34° E. The nonappearance of the Mescal limestone in the mine workings is an unsolved problem. It has either been engulfed in the diabase or was not deposited in this particular locality. About 1½ miles to the north, however, it appears in normal relations and full thickness; and 2 miles to the south, at the Belmont mine, many isolated large blocks of Mescal limestone are included in the diabase.

A large, extensively mineralized block of quartzite occurs in the diabase in the lower workings of the mine. This quartzite is believed to belong in the lower part of the Troy quartzite, but there is no conclusive proof that it is not a part of the Dripping Spring formation.

Cutting all the pre-Tertiary formations is a dike of quartz monzonite porphyry 5 to 20 feet thick, which strikes east and is approximately vertical. The youngest rocks are dikes of vesicular basalt which strike north, have a nearly vertical dip, and cut the youngest faults in the region.

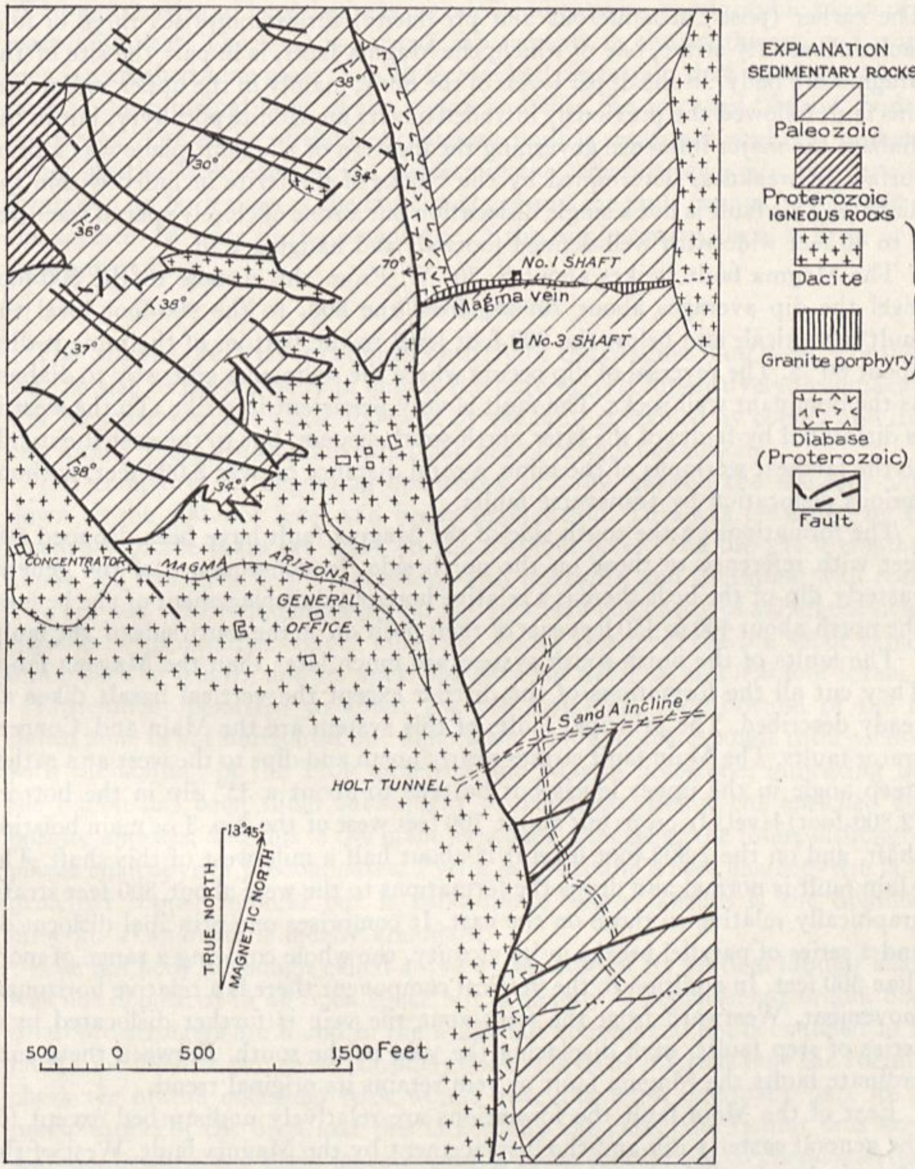


FIGURE 17.—Geologic map of the vicinity of the Magma mine, Superior, Arizona. (By I. A. Ettlinger and M. N. Short.)

Structure

Folds are subordinate in the region, but faults are widespread and of fundamental economic importance. (See fig. 17.) The faults are of two distinct ages. The earlier (post-Carboniferous and pre-dacite) series comprises three or four faults of easterly strike, one of which, the Magma fault, is in part the site of the Magma ore body. In the upper levels of the mine, mainly in the upper sediments, this fault followed the previously intruded quartz monzonite porphyry, but in the diabase the major influence governing the location of the fault plane was a prior surface of weakness determined by the blocks of quartzite included within the diabase. This fault is not a single dislocation but a zone of closely spaced fractures 5 to 40 feet wide with well-defined footwall and hanging wall.

The Magma fault strikes about S. 80° W. From the surface to the 800-foot level the dip averages about 70° N.; from the 800- to the 900-foot level the fault is vertical; and below the 900-foot level to the bottom of the mine it dips about 80° S. The reversal of dip occurs where the sediments give way to diabase as the dominant wall rocks. The fault is very persistent in strike. To the west it is dislocated by faults of the later north-south system, but to the east it extends to the farthest workings of the mine, a total distance of over 8,000 feet, without serious dislocation by transverse faults.

The formations on the south side of the Magma fault have been dropped 500 feet with reference to those on the north side. In consequence of the general easterly dip of the beds there is a relative horizontal displacement of the beds on the north about 400 to 450 feet east of their position on the south side of the fault.

The faults of the north-south system are much later than the Magma fault. They cut all the formations of the district except the vertical basalt dikes already described. The principal faults of this system are the Main and Concentrator faults. The Main fault strikes nearly north and dips to the west at a rather steep angle in the upper levels but flattens to about a 35° dip in the bottom (2,800-foot) level. It crops out about 700 feet west of the No. 3 or main hoisting shaft, and on the 2,800-foot level it is about half a mile west of this shaft. The Main fault is normal and drops the formations to the west about 800 feet stratigraphically relative to those on the east. It comprises one principal dislocation and a series of parallel breaks in its vicinity, the whole covering a range of more than 300 feet. In addition to the vertical component there is a relative horizontal movement. Westward from the fault zone the vein is further dislocated by a series of step faults, each displacing the vein to the south. Between these subordinate faults the Magma fault or vein retains its original trend.

East of the Main fault the formations are relatively undisturbed except for the general easterly dip and the displacement by the Magma fault. West of the Main fault a far different state of affairs exists. Most of the sedimentary formations have been covered by dacite, which conceals the structural relations, but here and there the dacite has been eroded away, revealing a veritable mosaic of fault blocks. In places small dacite remnants in the down-faulted blocks indicate that the faults are later than the dacite and presumably of the same age as the Main fault.

This complex block is bounded on the west and south by the Concentrator fault. Prior to exploration in the lower levels the Concentrator fault was believed to be subordinate to the Main fault. The Concentrator fault was cut on the 2,550-foot level, and here dacite is revealed, indicating a stratigraphic throw of at least 3,500 feet. The fault is normal, dips steeply to the southwest, and where seen is a crushed zone more than 10 feet wide. It is certain that the Concentrator fault is the principal fault of the region and that the so-called "Main" fault is misnamed. The strike of the Concentrator fault is southeast, and it is probably joined by the Main fault in the vicinity of the Superior town site, but here the formation on both sides of the fault is dacite and the fault cannot be followed on the surface. In spite of the magnitude of the displacement there is little or no escarpment here.

Ore deposits

The Magma ore body is confined entirely to the Magma fault zone. Considering the size of the ore body in depth, the outcrop is comparatively insignificant. The bleached porphyry dike followed by the fault is stained by copper and iron, and locally there are small isolated patches of residual chalcocite.

The company, on beginning operations in 1909, carried the 400-foot shaft down to the 800-foot level and began exploration. This was rewarded by the discovery of the main ore body on the 650-foot level. The ore shoot was here about 500 feet long and 5 feet wide, with quartzite and limestone wall rocks. The ore was very rich, consisting largely of steely chalcocite of supergene origin together with oxidized copper minerals. Above this level the ore shoot rapidly diminished in length, and its apex was between the 400- and 500-foot levels.

Enrichment persisted to about the 800-foot level. The bottom of the enriched zone is not horizontal but dips to the east and corresponds rather closely with the contact of the Troy quartzite and Martin limestone, indicating that the region has been tilted subsequent to oxidation. Below the enriched zone bornite appears, and this is the main hypogene mineral of the mine, although in places chalcopyrite predominates. Pyrite is abundant where chalcopyrite is the principal copper mineral but is subordinate where bornite is the dominant mineral. Tennantite is locally abundant.

The ore body, although called a "vein" because of its vertical tabular shape, was not deposited in an open space but is strictly of replacement origin. Some small ore stringers are found in the walls, but commercial ore is confined to the fault zone itself. From these considerations it is to be inferred that the chemical character of the enclosing rock would have played a dominant part in the precipitation of the ores, and this is actually the case. The richest ores are in diabase, because the basic igneous rock is more susceptible to chemical attack than the quartzites and shales of the lower sedimentary formations.

A feature of note is the absence of replacement ore bodies along the bedding of the upper limestones. At this horizon, as below, the ore body is confined to the fault and is short in comparison to its length on the lower levels, where diabase forms the walls.

Rock alteration by ore solutions was intense in the diabase within the fault zone but died out a short distance from both walls. The diabase was considerably altered by regional metamorphism before the advent of the ore solutions. Uralite, chlorite, and serpentine are widespread and in places give to the rock the appearance of a carbonaceous shale. Within the vein walls, however, the ore solutions have so completely altered the diabase that only the ghosts of a former diabase texture as shown by the microscope indicate the original rock. The dark minerals of the diabase have been completely bleached and the rock softened. The minerals now present are sericite and quartz. In hand specimens the altered diabase is indistinguishable from the altered porphyry of the upper levels.

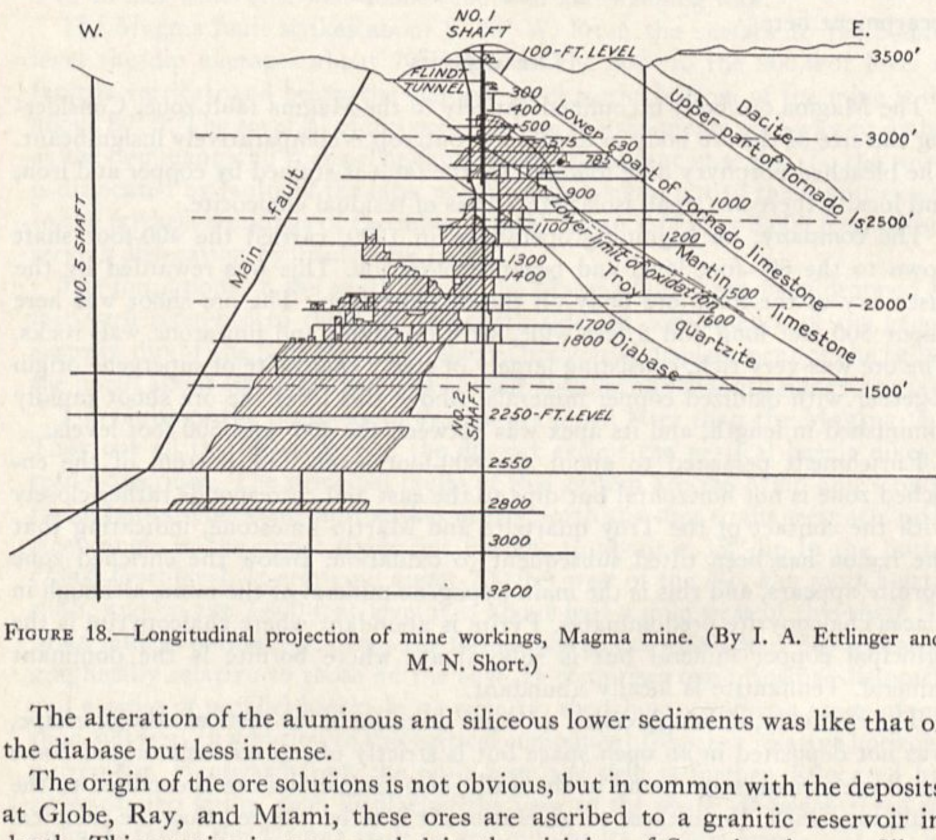


FIGURE 18.—Longitudinal projection of mine workings, Magma mine. (By I. A. Ettlinger and M. N. Short.)

The alteration of the aluminous and siliceous lower sediments was like that of the diabase but less intense.

The origin of the ore solutions is not obvious, but in common with the deposits at Globe, Ray, and Miami, these ores are ascribed to a granitic reservoir in depth. This granite is not revealed in the vicinity of Superior, but at Silver King, 2 miles to the north, is a small granitic plug. Furthermore, the granite porphyry dike already mentioned as occurring in the upper portions of the Magma fault may be an offshoot from the same subterranean granitic source. Several porphyry dikes have been located in the Magma mine by diamond drilling. These are not connected in any way with the Magma fault, and none of them are mineralized.

The Magma ore body east of the Main fault consists of two distinct shoots separated by about 400 feet of barren wall rock in their upper reaches, but these shoots approach each other and finally join below. (See fig. 18.) The upper and more easterly shoot has its apex between the 400- and 500-foot levels and is bottomed at about the 1,900-foot level. The lower and more westerly shoot has its apex a short distance above the 1,200-foot level and extends to the lowest levels of the mine. This apex is notable in that the ore contains no copper minerals but consists of sphalerite and galena. A short distance below the 1,200-foot level this changes abruptly into a rich bornite ore body with little or no lead and zinc. The same tendency for lead and zinc to occur on the margins of the ore body is shown in the easterly ore shoot. In passing eastward on any level the copper ores change abruptly into ores in which lead and zinc predominate. For some reason this feature is not observed on the western margin of the shoots. The axes of both ore shoots pitch decidedly to the west and are nearly at right angles to the dip of the beds, indicating that before the regional tilting the shoots stood nearly vertical.

The tenor of the Magma ores has always been high. This is fortunate, as the shapes of the ore body and the heaviness of the ground have kept the cost of mining high in comparison with that in the nearby porphyry-copper districts of Ray and Miami. However, this high tenor of the ore has made Magma one of the low-cost producers of the United States.

The lowest developed level is the 2,800-foot, but stoping operations have reached only to the 2,550-foot level. Before long the company will have opened up the vein on the 3,000- and 3,200-foot levels, which will make Magma one of the deepest copper mines in Arizona.

Morenci district

History and production

The Morenci district, near the New Mexico border, was discovered in 1870 by the Metcalf brothers, prospector members of a punitive expedition sent from Silver City, New Mexico, against an Apache raiding party. The discoveries were made on gold ledges north of Clifton. Two years later the two brothers led a gold prospecting party back to the district, but the gold showings proved disappointing, and on further search the rich copper outcrops at Morenci and Metcalf were found and staked. The best of these claims were sold in the following year to the Lezinskys, the principal merchants of Silver City. They organized the Longfellow Copper Co., built a 1-ton stone furnace at the mine, which was fed by carefully hand-sorted, oxidized ore running 25 percent or more in copper, and produced 900 pounds of 88 percent black copper a day. The black copper was hauled over 1,000 miles to St. Louis or Kansas City as ballast on the return trips of their otherwise empty supply trains. The venture proved a success from the start, and the output was gradually expanded in the following 9 years to 40 tons of ore a day by building a larger furnace at Clifton and by connecting the mine and the smelter by an inclined "baby gage" railroad using mule haulage. On the completion in 1882 of the Southern Pacific Railroad, which came within 36 miles of the mine, it was sold to Scotch capitalists, who reorganized as the Arizona Copper Co. During the 9 years of operation by the Longfellow Copper

Co., without railroad facilities, the remarkable production of 25,000,000 pounds of copper was made, worth over $5,000,000.

The Arizona Copper Co. was faced with a huge undertaking. The richest ore had been nearly exhausted, the price of copper fell to less than 10 cents a pound, the building of a 70-mile railroad to Clifton from Lordsburg was imperative, and expensive new development had to be undertaken. After 9 difficult years the property was finally put on a paying basis, largely through the efforts of James Colquhoun, the manager. A new smelter was built, and concentration and leaching of the tailing, both pioneer processes in copper mining, were successfully begun.

A second mining venture was launched in 1875 by E. B. Ward, of Detroit, and William Church, of Denver. A large group of claims at Morenci, adjoining the Longfellow mine, was acquired, and the Detroit Copper Co. was organized. After 6 years of development the financial aid of Phelps, Dodge & Co., of New York, was sought to build a smelter. Dr. James Douglas passed on the property, and on his recommendation a substantial interest was purchased. This was the introduction into mining of Phelps, Dodge & Co., who until then had been engaged solely in metal brokerage in New York. The Church and Ward interests were finally bought by the company in 1892.

Both companies slowly expanded operations, and in 1899 a third large company, the Shannon Copper Co., was organized, with holdings at Metcalf. Several smaller ventures were launched in the early years of the 20th century. The Shannon Copper Co. was finally absorbed by the Arizona Copper Co. in 1919, and the smaller ventures were acquired by the Detroit Copper Co. about the same time. Finally, in 1921, the Arizona Copper Co. was purchased by Phelps, Dodge & Co., and since then the two have been operated as a single unit by the Phelps Dodge Corporation, Morenci branch. The merging of the two companies permitted the exploitation of the largest ore body as a single operation and also allowed the successful prospecting of a very large low-grade disseminated-sulphide body, both formerly held jointly. A large tonnage has been developed, and plans to exploit the deposit had reached maturity by 1932, when the unfavorable copper market forced suspension of operations.

Metal production of Morenci district

Source	Period	Copper (pounds)	Silver (ounces)	Gold (ounces)	Total value
Longfellow Copper Co.	1873–82	24,914,000	....	....	$5,481,080
Detroit Copper Co.	1882–1919	458,870,481	956,844	24,748	73,683,023
Arizona Copper Co.	1883–1921	843,913,120	....	....	137,708,178
Shannon Copper Co.	1903–18	171,562,296	607,169	17,687	28,895,823
Phelps Dodge Corporation	1922–29	375,318,074	895,577	29,031	55,550,865
Miscellaneous	1904–19	21,430,622	109,358	105	4,224,965
		1,896,008,593	2,568,948	71,571	305,543,934

Topography

The Morenci district is on the northeast edge of the mountain area close to the Arizona-New Mexico line, at the head of a northwestward-trending intermontane plain. Southeast of the district this plain is bounded by the Steeple Rock Range on the northeast and the Peloncillo Mountains on the southwest, but at Clifton it ends abruptly against the escarpment of the Colorado Plateaus. The escarpment is much dissected by the canyons of the San Francisco River and its southeasterly tributaries, Chase Creek and Apache Gulch, into rugged mountains linking the northwest ends of the Steeple Rock and Peloncillo Ranges. The mineral deposits of the district are in this area.

The plain at Clifton, at the junction of the San Francisco River and Chase Creek, is about 3,500 feet above sea level. Morenci is at the head and on the steep sides of Morenci Gulch, a tributary of Apache Gulch, 4 miles northwest of Clifton, about 4,800 feet above sea level. Metcalf, 2 miles north of Morenci, is about 400 feet lower, in the canyon of Chase Creek. The mines of the district are between Morenci and Metcalf, on the mountain slopes on both sides of Chase Creek. The maximum altitude is at Copper King Mountain, 6,800 feet above sea level. The mineralized area is about 6½ by 4 miles.

The district is served by a 70-mile broad-gage branch of the Southern Pacific Railroad from Lordsburg to Clifton. It is connected by the Coronado Trail, an improved highway, with the Lordsburg-Benson-Tucson highway, which it joins near Bowie. The Coronado Trail continues north of Clifton as a spectacular mountain road, built up Chase Creek and over the high pine-covered mesas of the White Mountains to Springerville.

Sedimentary rocks

The basement rock is a pre-Cambrian granite, consisting of orthoclase, albite, quartz, and biotite (11, p. 56). It crops out below erosion remnants of Paleozoic sediments in the high mountains east and west of the Chase Creek Canyon. (See pl. 11.) The granite outcrops are reddish, owing to finely disseminated ferric oxide inclusions in the orthoclase. It is prominently sheeted by northeasterly or northerly vertical joints. Over a peneplaned surface of the granite lies a succession of Paleozoic sediments, starting with the Coronado quartzite, which attains a maximum thickness of 250 feet. The base of the quartzite is usually composed of a quartz-pebble conglomerate as much as 50 feet thick. Its age is probably Middle Cambrian. It is conformably overlain by the Longfellow limestone, with a maximum thickness of 400 feet. The lower 150 feet is sandy limestone, which grades up into cherty-banded dolomite. Fossils in the bottom beds were tentatively assigned to the Middle Cambrian by Walcott; Ordovician (Beekmantown) trilobites and brachiopods are found in the upper beds.

The Longfellow limestone is capped, apparently conformably, by the Morenci shale, 175 feet thick. The lower 75 feet is compact shaly limestone, not present in all sections, and above the limestone is 100 feet of fissile black shale. The limestone member contains an Upper Devonian fauna closely allied to the Martin limestone fauna of Bisbee and Globe. Although the Morenci is apparently conformably above the Longfellow limestone, the absence of Silurian and Devonian sediments indicates a considerable unconformity between the two formations. The Morenci is overlain conformably by the lower Mississippian Modoc limestone, 170 feet in maximum thickness. About 8 miles north of Metcalf the Modoc is capped by the Pennsylvanian Tule Spring limestone, of which a considerable thickness crops out, capped by the volcanic succession of the White Mountains.

In the southern part of the Morenci district the Paleozoic rocks are overlain by the Pinkard formation, which consists of several hundred feet of sandstone and shale. The attitude is almost identical with that of the underlying Paleozoic beds, but there is a slight unconformity. The Pinkard rests on beds at various horizons from the Longfellow limestone to the Mississippian Modoc limestone and is of Upper Cretaceous (Colorado) age. Considerable post-Paleozoic and pre-Cretaceous faulting is indicated, followed by erosion and much channeling. Overlying a faulted complex of all the preceding rocks, together with igneous intrusives and a thick covering of extrusive rocks, is the Gila conglomerate. This is partly consolidated and consists of poorly sorted boulders and sand derived from all the older rocks. It attains a maximum thickness of several thousand feet and is a filling of the intermontane plain south of Clifton and in the lower canyons of the San Francisco River and Chase Creek, where it is now being deeply trenched.

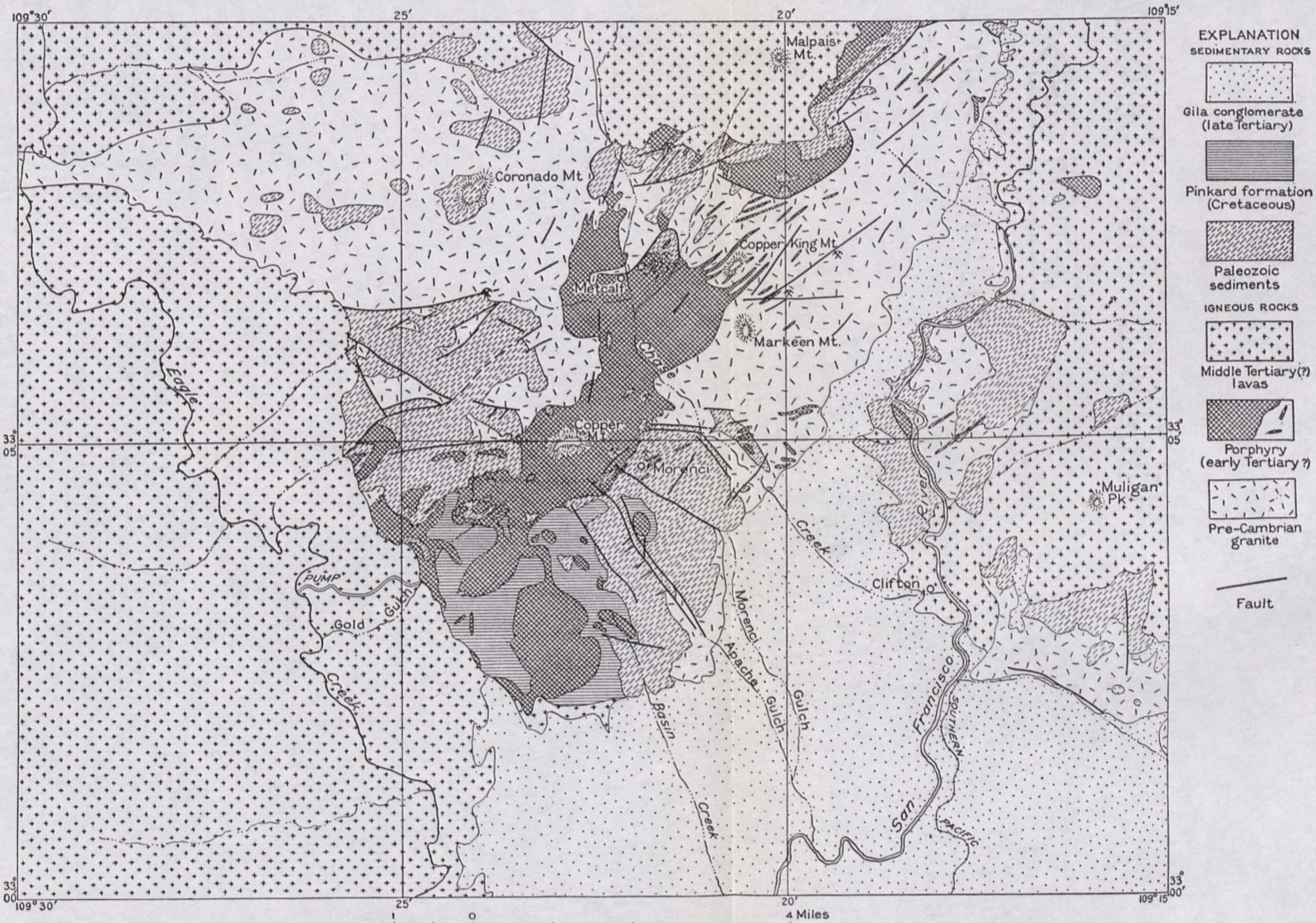
Igneous rocks

Intruding the pre-Cambrian granite and the overlying Paleozoic and Cretaceous formations is a large stockwork of porphyry, which crops out in a northeastward-trending belt from Gold Gulch, 3 miles southwest of Morenci, to a point 5 miles northeast of Metcalf, a total length of 10 miles. The belt is widest at its southwest end, where the porphyry is capped by later extrusive rocks. It is here 3 miles wide and has intruded the Pinkard and underlying formations as thick sills. At Copper Mountain, northwest of Morenci, it forms a stock 1¼ miles wide, extending northeast to Metcalf, where it is about 2 miles wide. Northeast of Metcalf it forms a closely spaced group of northeastward-striking dikes and small stocks, intruding pre-Cambrian granite and small remnants of Paleozoic sediments. At its northeast end it is again covered by later extrusives.

The porphyry southwest of Morenci is characteristically a diorite porphyry, which grades insensibly northeastward into a quartz monzonite porphyry. From Morenci to Metcalf alteration by mineralized solutions has added much quartz, pyrite, and sericite, and fresh outcrops are rare. The least-altered specimens obtainable indicate it to be here a quartz monzonite porphyry. Near Metcalf the most acidic phase, a granite porphyry, is found. To the northeast it again becomes more basic.

A few small dikes of diabase intrude pre-Cambrian granite, Coronado quartzite, and the porphyry. They are probably minor differentiates of the porphyry.

Separated in time by a long erosion period is a thick extrusive succession derived from vents in the Colorado Plateaus, to the north. They are predominantly basalts with minor amounts of rhyolite, rhyolite tuffs, and andesitic lavas, tuffs, and breccias. They are not mineralized in this district and are older than the Gila



GEOLOGIC MAP OF THE MORENCI DISTRICT, ARIZONA

After Waldemar Lindgren.

conglomerate, which overlies them to the southeast. They have been little involved in the faulting and probably covered a surface of considerable relief.

Structure and geologic history

The faults and porphyry intrusive, which were intimately associated with ore deposition, trend as a rule east to northeast. Generally this system of faults repeatedly stepped down the involved blocks to the southeast. Some of these faults have throws measured in thousands of feet. They are the oldest dislocations of the district and antedated or accompanied the intrusion of the porphyry, many dikes of which follow the faults. A long period of erosion followed the faulting and intrusion, developing a surface of very considerable relief. Probably a deep depression was left which was followed by the present course of the San Francisco River northeast of Clifton. This depression coincides with one of the largest northeast faults, which has a throw of over 3,000 feet down to the southeast. Over this irregular surface was then deposited a thick series of lavas, tuffs, and breccias ejected from vents to the north. After the volcanism or possibly toward its end the area was folded and faulted along northwest axes, developing, southeast of the district, the Peloncillo and Steeple Rock Mountains and the low basin between them. The Morenci district, at the northwest end of the low area, was less affected by the diastrophism than the area to the southeast, but many northwestward-striking faults of small throw, accompanied by tilting of about 15° to the southwest, developed here. Vigorous erosion followed, stripping off the extrusive rocks, and part of the district was probably covered by Gila conglomerate. The old northeastward-trending low area now followed by the San Francisco River was again exposed by the removal of the fill of volcanic rocks. The age of the northwest faulting in the district is not directly known, as the volcanic rocks have been completely removed. The faults of this series are later than the porphyry and ore deposits, and although of comparatively small throw, the three largest are conspicuously followed by the present courses of Apache Gulch, Morenci Gulch, and Chase Creek. The system is in alinement with the intermontane plain developed to the southeast after the eruption of the lavas that crop out in the bordering ranges, and the southwesterly tilting involved the lavas at the southwest end of the district.

The erosion that succeeded the diastrophism was finally followed by the general uplift of the mountain area and Colorado Plateau to their present altitude. At Morenci this uplift did not renew the old faults or develop new ones. The attitude of the Gila conglomerate is virtually level. The extensive trenching of the conglomerate, now in progress, is probably due to the Gila River cutting its channel through the Peloncillo Range after the uplift. The intermontane plain southeast of the district, which prior to the uplift was essentially an internally drained basin, was thereby added to the drainage system of the Gila River. The present cycle of erosion, besides stripping the Gila conglomerate from the southeastern part of the district, has attacked the Colorado Plateau escarpment with increased vigor, thereby extending the exposures of the prevolcanic surface to the north and northwest.

Ore deposits [5]

The ore deposits of the Morenci district are of three general types. The most productive are wide lodelike deposits of disseminated-sulphide ore replacing porphyry and minor altered sedimentary inclusions, on the edge of the porphyry stocks. Second in rank are contact replacement deposits of oxidized and enriched sulphide ore in limestone, near the borders but away from the main porphyry stocks, associated with dikes and sills of porphyry. Ore bodies of this type furnished the rich ore mined in the early years and are now virtually exhausted. The ore bodies of the third type, also nearly exhausted of the better ore, are fissure veins of oxidized and enriched ore in pre-Cambrian granite and Cambrian quartzite, closely associated with porphyry and diabase dikes. In all the ore deposits, with the possible exception of the contact replacement deposits, the ore has resulted from enrichment and oxidation of material too lean to constitute commercial ore. The sulphides of this protore are chiefly pyrite with comparatively insignificant amounts of chalcopyrite and zinc blende. Specimens of protore are hard to obtain, as mine development has seldom extended below the zone of enrichment. The enriched zone is gradational from rich ore below the gossan cap (in which pyrite is completely replaced by chalcocite or oxidized to "limonite") through zones of increasing pyrite content and less chalcocite. The mineralized area is so high above the present permanent water table in the San Francisco River that the depth of the commercially enriched zone (the ore) varies in each ore body with the relative permeability of the deposit. Although most of the enrichment probably antedated the volcanism, it is still in progress. There is little evidence in the district of older water tables except in some of the tighter fissure veins in granite, where unaltered protore grades within a relatively short distance upward into enriched sulphide or oxidized ore, at higher altitudes than in the more pervious lodes in porphyry. In the contact replacement deposits oxidation and enrichment have extended to the bottom of the ore bodies, which are usually underlain by unreplaced limestone. Possibly the protore in these deposits was of higher grade than in the lodes and veins.

Lode deposits

The porphyry lode deposits of Morenci and Metcalf have produced most of the copper of the district, and virtually all the reserve tonnage of the camp is confined to one large lode deposit. These deposits occur chiefly in and on the southeast margin of the monzonite porphyry stock west and northwest of Morenci. Smaller similar lodes occur northeast of Metcalf, in Shannon Mountain. At both localities the porphyry intrudes Paleozoic limestones and shales, and the porphyry ores were discovered after the richer contact replacement deposits were developed.

The Morenci lode deposits are in Copper Mountain, west of Morenci. The porphyry stock is here about $1\frac{1}{4}$ miles wide and followed a large northeast fault with a throw of several thousand feet down to the southeast. On the northwest the porphyry is in contact with granite and basal Coronado quartzite. On the

[5] The description of the ore deposits is largely a digest of the work of Lindgren (11).

southeast side it intrudes Longfellow limestone and Morenci shale, large blocks of which are engulfed in a marginal zone 1,000 feet wide. The lode deposits in this complex of porphyry and sediments consist of replacement veins striking northeast and dipping steeply northwest. Each contains a central vein a few feet wide with well-marked dip and commonly with some gouge containing a relatively greater concentration of sulphides. Extending out into the walls is a zone of disseminated sulphides and irregular veinlets of sulphides, which gradually fades out away from the central vein. The most intense replacement occurred in the porphyry. The blocks of shale and dolomite were less impregnated by sulphides and commonly were replaced by epidote, pyroxene, and magnetite. Garnetization of the sedimentary xenoliths was rare in the lode deposits.

Originally the central veins alone were mined. With the increased efficiency of concentration more of the disseminated lower-grade ore was taken, until in the last 10 years the four principal veins with their border zones were included in a single wide low-grade ore body, the Humboldt, capable of being mined cheaply by caving methods. This ore body was mined over a length of about 2,000 feet and width of 600 feet (25, p. 1).

The porphyry was intensely altered and the feldspars sericitized by the mineralized solutions, leaving the quartz phenocrysts unchanged. Pyrite, with a little associated chalcopyrite and zinc blende, was introduced both in veinlets with little quartz and by replacement of the groundmass, with considerable quartz. Oxidation left light-colored blocky outcrops barren of copper stains and with little iron oxide. Owing to their silication, limestone and shale xenoliths better withstood oxidation and leaching. The capping ranges in depth from 100 to 200 feet and roughly follows the configuration of the surface. Rusty pyrite, in places associated with much secondary quartz, appears a few feet below the outcrop and persists throughout the zone of oxidation. Copper carbonates and oxides occur sparingly in the zone except in the sedimentary inclusions. The sericite remained unaltered by supergene waters both in the oxidized capping and in the underlying chalcocite zone. The chalcocite zone, with the richest ore at the top, is just below the oxidized cap. The pyrite was here almost completely replaced, but the replacement gradually diminished downward. In the southwestern part of the ore body lean protore without chalcocitization was reached at about 450 feet below the surface, with a comparatively sharp upper boundary. In the northeast end of the ore body, near the deep canyon of Chase Creek, the chalcocite zone has not been penetrated, and the bottom of the ore is purely economic. The maximum depth mined was 1,000 feet.

On the southeastern margin of the stock north of Morenci, where it intrudes granite and quartzite, a very large lode deposit occurs in which dissemination is general and there are no well-marked veins. The chalcocite zone is here deeper than in the southwestern part of the Humboldt ore body, and the zone is much larger in area. This ore body, the Clay, contains the large reserves of low-grade ore. Smaller lode deposits, in which the disseminated halo is poorly developed, occur in the northwestern margins of the stock west of Morenci and between Morenci and Metcalf. Northeast of Metcalf, on Shannon Mountain, the porphyry intrudes a small down-faulted block of Paleozoic sediments. Small lode deposits like those of the Humboldt ore body occur here in the larger dikes, but most of the ore forms contact-metamorphic replacement deposits.

Contact-metamorphic replacement deposits

The ore bodies of the contact-metamorphic replacement type have been virtually exhausted. They have been well described by Lindgren, who saw them in 1902, before mining of them had been completed (11, pp. 233–259, 323–337). They were best developed in the Paleozoic blocks at Morenci and at Shannon Mountain, where they were intimately associated with northeastward-trending porphyry dikes and sills away from the main porphyry stock. They were of two types—one exemplified by the Longfellow and Detroit ore bodies, bedded deposits that replaced Longfellow limestone and Morenci shale, and the other exemplified by the Joy ore body, a replacement vein in Morenci shale and porphyry.

In the bedded replacement deposits the ore (both oxidized and enriched sulphide ore) replaced Longfellow limestone, Morenci shale, and Modoc limestone near narrow dikes of sericitized porphyry which strike northeast and generally dip northwest. The limestone dips gently southwest. The Modoc limestone, which in many ore bodies caps the ore, was characteristically replaced by brown garnet, commonly copper-stained. The Morenci shale and limestone and the Longfellow limestone usually contain much epidote and magnetite. Most of the replacement ore bodies were oxidized throughout. The oxidized ore, especially in the argillaceous Morenci shale, contained much secondary kaolin.

In the replacement vein deposits the ore was more closely confined to the shear zone of the vein, and the wall rocks are much altered to garnet and epidote. In the Joy vein the oxide and enriched sulphide ore ended abruptly at a depth of 300 feet against solid pyrite containing a very little chalcopyrite and zinc blende, too poor in copper to constitute ore. Both types of deposits in Morenci were commonly displaced by small-throw faults of the northwest series.

The ore bodies on Shannon Mountain northeast of Metcalf resemble those at Morenci. Silication of the limestones and shales was not as vigorous as at Morenci, so that the oxidizing waters contained abundant carbonic acid, which fixed the copper as carbonate. In the bottom levels of one deposit, in Morenci shale, primary low-grade ore consisting of disseminated pyrite and chalcopyrite occurs.

Fissure-vein deposits

The ore bodies of the fissure-vein type have replaced the fault breccias in faults cutting granite and quartzite. The largest of these deposits, the Coronado vein, crops out on the southern slope of Coronado Mountain, west of Metcalf. The ore body follows a fault striking nearly east and dipping steeply south, with granite on the footwall and Coronado quartzite on the hanging wall. The fault breccia, from 50 to 200 feet wide, and a diabase dike intruding it are the hosts for the ore body. The outcrop was a limonite-stained silicified granite-quartzite breccia containing shoots of rich oxide and carbonate ore. At shallow depth the oxidized ore changed to chalcocite ore associated with kaolin in a gangue of silicified breccia. At about 300 feet below the surface pyrite coated with chalcocite appears and grades downward in a few hundred feet into pyritic protore of the usual Morenci type. Smaller ore bodies of this type occur in Copper King Mountain, east of the main porphyry stockwork, in the fault breccias of northeastward-striking faults cutting granite. Shoots of oxide and carbonate ores crop out and give way rapidly in depth to lean protore with a relatively shallow chalcocite zone intervening.

Northeast of Metcalf, from Placer Gulch to and beyond Sycamore Gulch, connecting porphyry stocks crop out for 3 miles in contact with pre-Cambrian granite and Paleozoic sediments. The porphyry is here more basic, approaching a diorite, and was not followed by mineralizing solutions.

Summary

The ore deposits of the Morenci district are associated with a large stockwork of porphyry which intruded, along a northeastward-striking system of faults, a complex of pre-Cambrian granite and Paleozoic and Mesozoic sediments. The porphyry ranges from a quartz diorite at each end to quartz monzonite and granite porphyry in the greater part of its length. The ore deposits are essentially replacement deposits of both porphyry and intruded rocks, near the contacts of the more acidic phases of the porphyry. The replacement was effected by silicic solutions carrying iron sulphides and subordinate copper and zinc sulphides. The value of the ore is due to enrichment of the original lean protore into chalcocite ore, followed commonly by the oxidation of the chalcocite.

Three postmineral erosion cycles with two intervening periods of uplift have been recognized. Probably most of the enrichment was effected in the first two cycles, and in the more vigorous present cycle erosion is outstripping enrichment and exposing the older chalcocite zones to oxidation and erosion.

Bisbee district [6]

History and production

The rich copper outcrops at Bisbee were discovered in 1877 by army officers and scouts. In 1879 the Copper Queen Mining Co. was organized to exploit the deposit. In 1880 Phelps, Dodge & Co., through the advice of Dr. James Douglas, purchased ground adjoining the Copper Queen. In 1884 the two companies were merged into the Copper Queen Consolidated Mining Co. under the control of Phelps, Dodge & Co.

During the next 16 years the Copper Queen Consolidated absorbed most of the surrounding ground and gradually expanded its scale of operations. In the late nineties Phelps, Dodge & Co. decided to build a smelter town in the Sulphur Spring Valley, 20 miles east of Bisbee, and to build a railroad from El Paso, Texas, to the new smelter town of Douglas, Arizona, on into Bisbee, and beyond to Benson, connecting there with the Southern Pacific Railroad. On completion of this road the company purchased the El Paso & Northeastern Railroad, which extended the line from El Paso to the Chicago, Rock Island & Pacific Railroad

[6] The description of the Bisbee district is largely summarized from the publications on the district (13, 27).

terminus at Tucumcari, New Mexico. The work was completed by the end of 1903, and the annual output of copper was more than doubled.

Until 1900 the Copper Queen Consolidated Mining Co. was the only operator in the camp. In 1900 large groups of claims were purchased by capitalists from the copper and iron districts of the Great Lakes, and the Calumet & Arizona and subsidiary companies were organized to exploit the ground. By the end of 1902 high-grade ore had been developed and a smelter erected at Douglas. Other smaller ventures, notably the Shattuck-Arizona and Denn-Arizona, were also started at this time.

All these companies continued mining and developing without interruption during the next 25 years, and the Copper Queen Co. increased its production still further by exploiting two large bodies of disseminated ore in the central porphyry core of Sacramento Hill.

At the end of 1931 the two largest companies, the Copper Queen and the Calumet & Arizona, were consolidated as the Phelps Dodge Corporation, Copper Queen branch. The Shattuck mine had previously been consolidated in 1925 with the Denn mine by the Shattuck-Denn Mining Corporation. At the present time (1932) there are thus two operating companies in the camp, both with large reserves of high-grade ore, insuring a productive life of many years to the district.

The Bisbee district has produced, besides copper, considerable amounts of other metals, notably gold and silver, which occur with the copper ore and are recovered in refining. Considerable lead-silver ore has also been mined in the past, but such ore is now nearly exhausted. Smaller tonnages of lead-zinc ore have been mined, and during periods of favorable market conditions high-grade manganese ore is mined and shipped to Bessemer plants on the Atlantic coast.

The production of the several metals to the end of 1929 is stated below:

Copper:		
Early production, 1880–1901	pounds	338,568,058
Copper Queen, 1902–29	do	2,121,665,023
Calumet & Arizona, 1902–29	do	1,261,190,224
Shattuck and Denn, 1906–29	do	152,464,825
Miscellaneous, 1909–20	do	14,641,142
		3,888,529,272
Lead, 1908–29	do	148,425,188
Silver, 1895–1929	ounces	41,524,193
Gold, 1895–1929	do	1,110,058
Zinc, 1917–26	pounds	14,169,579
Manganese ore, 1918–29	tons	42,397
Total value, 1880–1929		$704,421,404
Normal annual production rate		$25,000,000
Maximum annual production (1917)		$47,880,400
Dividends paid, 1885–1929 (approximate)		$222,500,000

Topography

The Bisbee district is in the southeast end of the Mule Mountains, in the southeast corner of Arizona. The range starts at the Mexico-Arizona line, 6 miles east of Bisbee Junction, as a low narrow ridge, and rises gradually northwestward to a point 3 miles east of Warren, where it spreads out as a mountain mass 12 miles wide. Thence it extends, with this width, 15 miles northwestward to an alluvium-covered pass between Sulphur Spring Valley and San Pedro Valley, northwest of which are the Tombstone Hills and the Dragoon Mountains. The range is bounded on the northeast by the broad Sulphur Spring intermontane plain and on the southwest by the narrower plain drained by the San Pedro River.

The range comprises two distinct parts separated by a deep, narrow valley. This valley heads in the center of the mountains at Mule Pass, 6,038 feet above sea level. Northwest of this pass is the northwestward-draining Tombstone Canyon, and southeast of it is the southeastward-draining Mule Gulch. The main highway from Douglas to Tombstone follows this depression. Northeast of the depression the range is a wide dissected cuesta carved from gently northeastward-dipping Comanche (Lower Cretaceous) sandstones, shales, and limestones. Southwest of the depression is the bold, rugged Escabrosa Ridge, carved from an intricately folded and faulted complex of indurated pre-Cambrian and Paleozoic rocks and large masses of intrusive porphyry and rhyolite.

The highest point in the range is Mount Ballard (7,400 feet), on Escabrosa Ridge. The lowest points are at the two ends, where the altitudes are 4,800 feet at the northwest and 4,400 feet at the Mexican border.

The range is sharply separated from the alluvium-filled plains to the northeast and southwest. The plains slope away from the mountains at the rate of 25 to 30 feet to the mile, as contrasted with rock slopes in the range, which reach 100 to 500 feet to the mile on the northeast side and 500 to 1,000 feet to the mile on the southwest side.

Sedimentary rocks

The basement rock in the district (see pls. 12, 13; fig. 19) is the Pinal schist, resembling that of the Globe-Miami and Ray areas, already described. Near the porphyry intrusives it has commonly been altered by the introduction of disseminated pyrite, the schistosity being nearly obliterated. In Juniper Flat, northwest of the mineralized area, it was intruded in pre-Cambrian time by a large stock of normal coarse granite with porphyritic dike apophyses.

On a peneplaned surface of schist in the mineralized area were deposited over 5,000 feet of Paleozoic sediments, starting with 430 feet of the Middle Cambrian Bolsa quartzite, conglomeratic at the base and increasingly fine-grained toward the top. This formation is not fossiliferous but is followed conformably by the Abrigo limestone, 720 feet thick, in which a Middle Cambrian fauna occurs in the basal beds and Upper Cambrian faunas through most of its thickness. The Abrigo is capped conformably by the Copper Queen formation, 50 feet thick in one exposure but possibly absent in others, in which a topmost Cambrian fauna is found. The two formations are very similar lithologically and consist of sandy dolomitic limestones, shaly at the bottom, characteristically banded by epidote. The Copper Queen is overlain by the Parting quartzite, ranging from a knife edge to 25 feet in thickness. Disconformably overlying the Parting quartzite is

System	Series	Formation		Thickness: Feet	Thickness: Meters	Character
Cretaceous.	Comanche (Lower Cretaceous).	Cintura formation.	Kc	1,800+	549+	Red nodular shales with cross-bedded buff, tawny, and red sandstones; a few beds of impure limestone near base.
		Mural limestone.	Km	650	198	Thick-bedded hard gray fossiliferous limestone. Thin-bedded arenaceous dark fossiliferous limestone.
		Morita formation.	Kmr	1,800–2,000+	549–610+	Buff, tawny, and red sandstones and dark red shales, with an occasional thin bed of impure limestone near the top.
		Glance conglomerate.	Kg	25–1,000	7.6–305	Bedded conglomerate with rather angular poorly assorted pebbles of schist, quart ite, and limestone. Rests on irregular surface of erosion.
		—Unconformity—				
Carboniferous.	Pennsylvanian, Permian.	Naco limestone.	Cn	3,000+	914+	Principally light-gray compact limestone in beds of moderate thickness, with very subordinate shale. Contains abundant fossils.
		Granite porphyry and andesite porphyry.	gp Pa			Erupted into all formations.
		—Disconformity—				
	Mississippian.	Escabrosa limestone.	Ce	700	213	Thick-bedded white and light-gray granular limestone. Contains abundant crinoid stems.
Devonian.	Upper.	Martin limestone.	Dm	340	104	Dark-gray fossiliferous limestone in beds of moderate thickness, with subordinate pink calcareous shale.
		—Disconformity—				
Cambrian.	Upper.	Abrigo limestone.	€a	770	235	Thin-bedded epidote-banded limestones with some calcareous shales, sandy toward the top, capped by 8 to 15 foot bed of white quartzite.
		Bolsa quartzite.	€b	430	132	Moderately thick cross-bedded quartzite and arkosic grits with basal conglomerate. Rests on peneplaned surface of schist and granite.
		—Unconformity—				
Archean.		Pinal schist.	ps			Sericite-quartz schist.
		Granite and granite porphyry.				Intrusive in the schist.

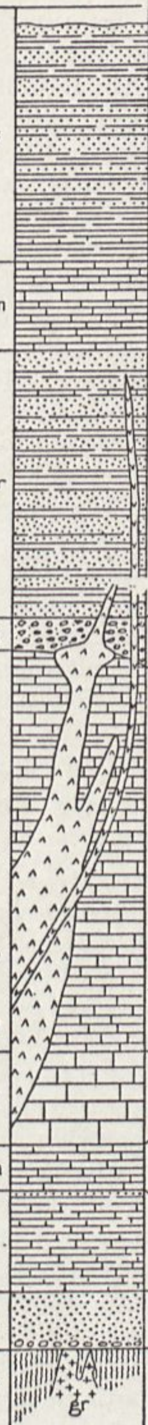
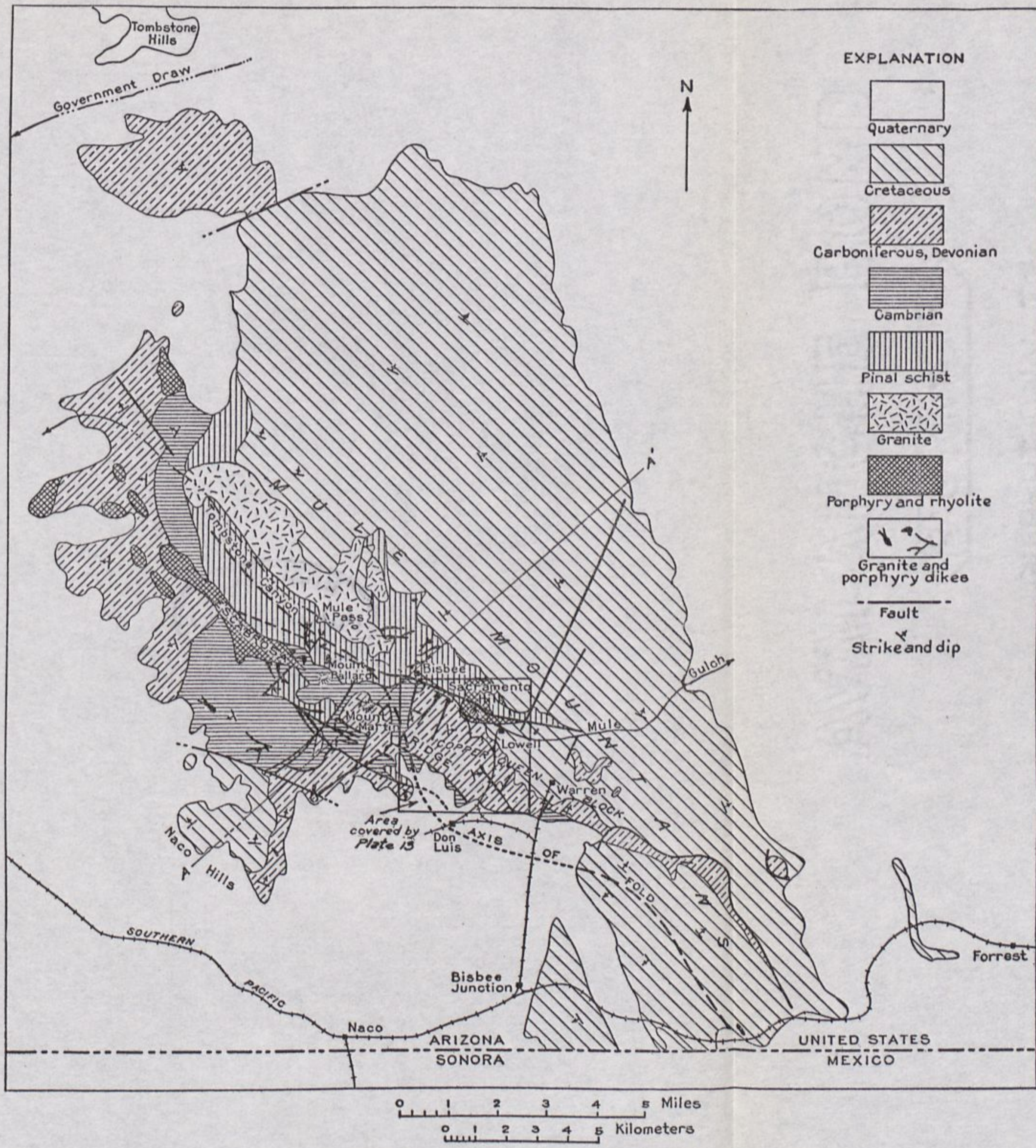
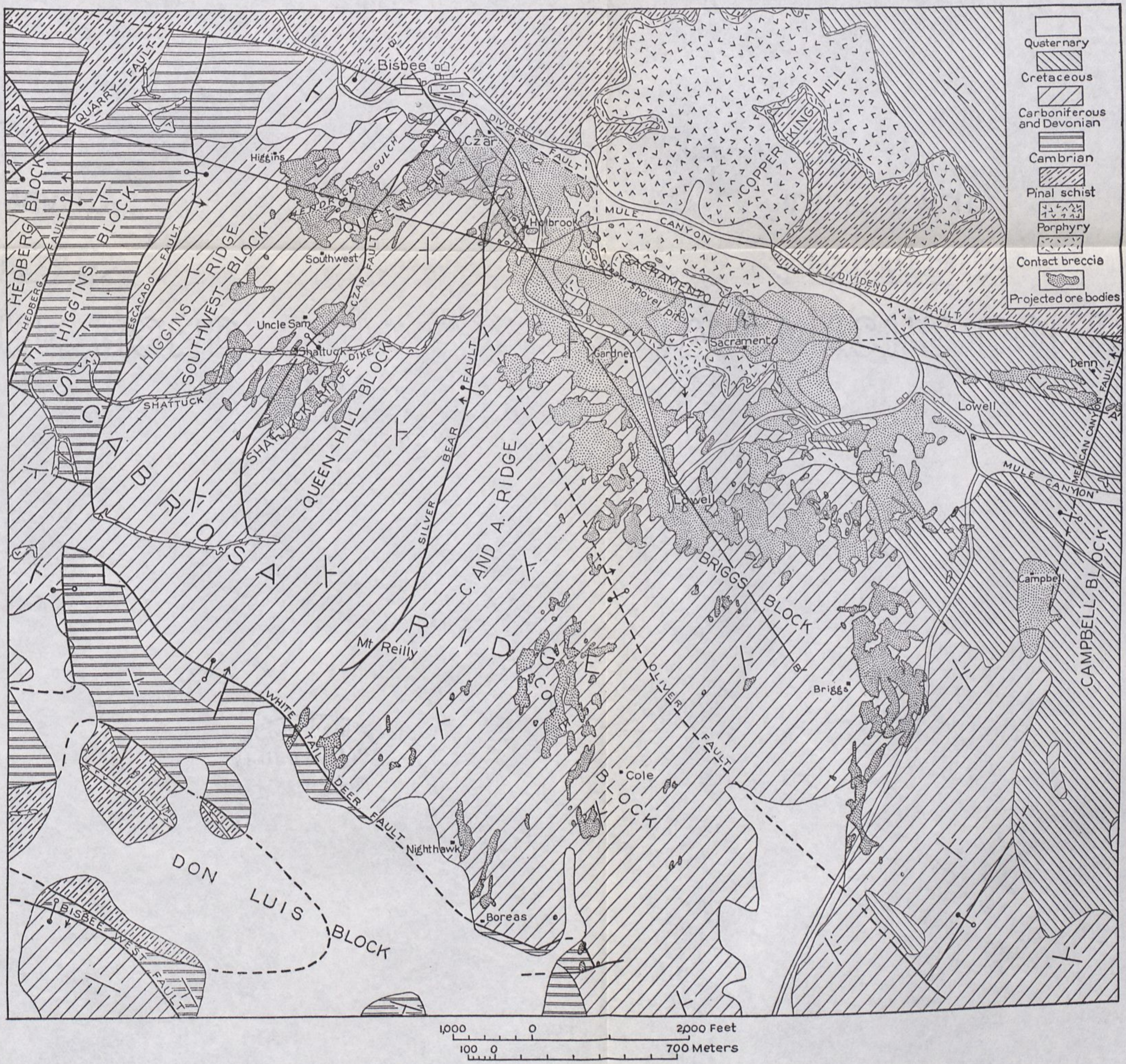


FIGURE 19.—Columnar section of the Bisbee district, Arizona.



GEOLOGIC SKETCH MAP OF THE MULE MOUNTAINS, ARIZONA

For section along line *A–A'* see 16th Internat. Geol. Cong. Guidebook 14, fig. 3.



GEOLOGIC MAP OF THE BISBEE DISTRICT, ARIZONA

For sections along line *A–A'* see 16th Internat. Geol. Cong. Guidebook 14, pl. 13; for vertical projection along line *B–B'*, idem, fig. 4.

the highly fossiliferous Upper Devonian Martin limestone, about 340 feet thick. No apparent unconformity exists at its base, although the disconformity represents all of Ordovician, Silurian, and Lower and Middle Devonian time. The Martin limestone grades through a transition zone of pink dense limestone into the overlying Escabrosa limestone, of lower Mississippian age. The Escabrosa is characteristically thick-bedded limestone with considerable chert as irregularly banded nodules at certain horizons. It is about 700 feet thick and grades without apparent unconformity, except through local sandy beds, into the overlying Naco limestone, of lower Pennsylvanian age. The lower members of the Naco greatly resemble the Escabrosa limestone but grade upward into limestone with abundant chert nodules intercalated with limy shale. The top of the Naco is eroded, and its former thickness is unknown, but at least 3,000 feet is present in the deeper shafts at the east end of the district.

Overlying an uneven erosion surface of all older rocks is a succession of Lower Cretaceous sediments 4,200 to 5,200 feet thick. The Glance conglomerate, composed of poorly sorted boulders predominantly of schist and quartzite, cemented by sand, is the basal formation. It filled in the hollows of the old surface and ranges in thickness from a few feet to several thousand feet. It is capped by the Morita formation, 1,800 feet thick, composed of sandstones and sandy shales containing characteristic argillaceous concretions. Overlying an intermediate zone of sandy limestones is the conspicuous wall-like cliff of the massive-bedded Mural limestone, 650 feet thick, containing abundant Lower Cretaceous fossils. This is followed by the Cintura formation, composed of quartzitic sandstones and shales, as much as 1,800 feet thick. Its top is removed by erosion.

The only other sedimentary rocks are the Recent fluviatile deposits in the gulches, some of which have been well cemented. On some of the hillsides recent landslide detritus covers small areas.

Igneous rocks

Many small stocks, dikes, and sills of granite porphyry cut the formations in Escabrosa Ridge. The Cretaceous sediments have been completely eroded. On the northeast side of the range disturbance has been slight, and no porphyry occurs. Where the southeast extension of Escabrosa Ridge is partly covered by the basal Cretaceous, a few dikes of granite porphyry and andesite porphyry cut the Cretaceous beds. The Sacramento Hill mass of porphyry, one of the largest outcropping igneous masses, is bounded on the north and east by Cretaceous sediments, but the relations are obscure. It is apparently normally overlain by Glance conglomerate to the southeast, yet apparently it cuts the conglomerate and overlying Morita formation to the north. Underground exploration has shown that the porphyry spread out as a laccolith beneath the Glance conglomerate, suggesting that the southeastern contact is also intrusive. Other indirect evidence also points to the post-Cretaceous age of the porphyry intrusion (26, p. 52).

The porphyry is a light-gray rock containing abundant phenocrysts of feldspar, quartz, and biotite. The groundmass makes up one-half to eight-tenths of the rock. The rock ranges from granite porphyry to quartz monzonite porphyry, but the acidic phase predominates. Rhyolite porphyry dikes with well-developed flow lines and glassy groundmass are common.

Closely associated with the porphyry, but distinctly later, are small dikes and sills of hornblende andesite.

Structure

The dominating structural feature in the Mule Mountains is an elongated dome with a northwesterly axis, steeply dipping southwestern flanks, and gently dipping northeastern flanks. Owing to the great competence of the Paleozoic sediments, the doming broke the mountains into large fault blocks bounded by both normal and reverse faults. Many wedgelike blocks were overthrust toward the axis of folding. On the steep southwestern flanks of the fold, where shattering was greatest, the fault zones, which strike dominantly northwest, were invaded by a long stockwork of porphyry dikes and small interconnected stocks for a total length of about 12 miles and an average width of about a mile. The southeast end of this stockwork is the Sacramento Hill porphyry, which is intimately connected with the greater part of the ore of the district. The present structure of the range was superimposed on pre-Cretaceous structure controlled by faults of large throw striking west-northwest and dipping steeply. The Paleozoic rocks were very little tilted, but on the footwall (north) side of the largest fault, the Dividend fault, pre-Cretaceous erosion almost completely stripped the Paleozoic sediments, exposing the pre-Cambrian schist in the mineralized district and pre-Cambrian granite to the northwest. The hanging-wall side of the fault was less vigorously eroded, and a large part of the Paleozoic sediments was left intact. The subsequent sinking into the Cretaceous sea occurred before erosion had leveled the surface. Hollows as much as 1,000 feet deep were filled, as sinking proceeded, by the coarse detritus of the Glance conglomerate, derived largely from the footwall side of the Dividend fault. The late Cretaceous or early Tertiary diastrophism was probably governed in large part by the relative strength of the footwall as compared to the hanging wall of the Dividend fault, and the axis of folding closely followed the fault.

The mineral district is confined to one large fault block northeast of the main axis of folding of the range. The pre-Cretaceous Dividend fault, striking nearly east, cuts through the district and virtually marks its northern boundary. The sediments in the block dip generally east and northeast at about 15° and have been extensively cut by northeasterly faults, on most of which the southeast side is relatively raised. A large mass of porphyry about 4,000 feet in diameter, which ascended as a plug along the Dividend fault, invaded both the footwall schist and the Paleozoic hanging-wall sediments. It mushroomed out against the bottom of the Glance conglomerate on the hanging-wall side, where the conglomerate was between 600 and 1,000 feet thick, and cut through it on the footwall side, where it was not over 20 feet thick. Several smaller dikes that cut Paleozoic sediments also crop out, and many larger plugs, dikes, and sills, independent of Sacramento Hill and not exposed at the surface, have been cut by exploratory work.

In the southeast corner of the State the early diastrophism accompanying intrusion and ore deposition did not develop along northeast axes, as in central Arizona. Northwestern alinement was probably established in late Cretaceous time, when the thick clastic rocks in the Cretaceous geosyncline trending northwestward were deformed. In all the mountain ranges in this belt the intrusive stocks trend generally northwest, in contrast to the northeasterly trends in central Arizona. Intrusion was followed here, as in central Arizona, by a quiescent erosion cycle, after which, in many ranges but not in the Mule Mountains, volcanic rocks were extruded. Later uplift was renewed along the old northwest axes. After a second long erosion cycle came the last general uplift in southeastern Arizona, accompanied by almost no differential movement between mountain and intermontane plain blocks. The movement is attested by the trenching of the valley fills in the San Pedro and other valleys due to increased gradients.

Ore deposits

The ore deposits were formed essentially by the replacement of both Paleozoic sediments and porphyry, closely associated in time and place with porphyry intrusions. Part of the mineralization certainly occurred in late Cretaceous or early Tertiary time, and probably all is to be assigned to that period. The evidence is clouded, however, and there is a possibility that porphyry intrusion began in early Mesozoic time and was revived in the late Mesozoic or early Tertiary and that mineralization may have occurred during both periods, separated by a quiescent cycle of sedimentation in which at least 5,000 and probably nearer 15,000 feet of Lower and Upper Cretaceous sediments were deposited.

The ore deposits are clustered around more or less independent centers of mineralization, as a rule closely associated with independent centers of porphyry intrusion. The largest of these centers, the Sacramento Hill porphyry, has produced most of the ore mined in the past, but there are six smaller centers, one of which is now being actively exploited. Mineralized outcrops are found several miles east and southeast of prospected ground, and probably other centers, as yet unrecognized, exist in this area.

The ore deposition in each center differed from that in others, especially in stratigraphic horizon. In general, in each center certain definite strata, generally limestones, varying from a few hundred to 700 feet in thickness, were selected for replacement. Below and above the favorable beds only relatively insignificant mineralized fissures occur. In the Sacramento Hill center the ore occurred in a wide aureole of limestone replacement deposits south of the Dividend fault. No ore occurred in the schist north of the fault. The favorable strata in this center included the top 150 feet of Cambrian and the lower 200 feet of Mississippian limestones, with the intervening beds, a total thickness of 700 feet. The ore cropped out west of Sacramento Hill, but the eastward dip carried it down to the east at about 15° until on the east side of the porphyry, more than a mile away, the zone was from 1,500 to 2,200 feet below the surface. Disseminated sulphide ore also occurs within the Sacramento Hill porphyry, closely following the limestone contact south of the Dividend fault. This ore body also dipped east and was several hundred feet above the limestone ore zone. In the thick limestone ore zone ore bodies are erratically distributed, being localized by faulting, porphyry intrusion, and more favorable beds.

The minerals of the deposits are quartz, sericite, chlorite, serpentine, abundant pyrite, chalcopyrite, bornite, and some galena and zinc blende. The limestone was in places marbleized and near the contacts was largely replaced by tremolite, wollastonite, and sericite. In the ore bodies themselves the limestone was replaced by silica, pyrite, and chalcopyrite, commonly with later bornite. Much of the limestone ore mined was oxidized or enriched sulphide ore, most of which has been exhausted.

In the porphyry ore bodies the porphyry was intensely shattered. The fractures were filled by quartz, pyrite, chalcopyrite, and bornite, and much pyrite was disseminated between them. The ore was deposited as an inclined blanket, which has since been enriched to the bottom, where the contacts with relatively sparsely mineralized, sericitized porphyry are sharp.

In the other centers there were differences in mineralogy as well as in horizon. In two smaller centers abundant quartz replaced the limestone as bodies of silica breccia, around which the later sulphides of copper and lead were deposited. The Campbell, the latest center to be exploited, is a mile east of Sacramento Hill and is associated with a northeastward-striking dike of porphyry, which did not crop out. The ore zone here is the thickest of all yet found, and the ore body differs in shape from those of the other centers, being more lodelike as contrasted to the flat tabular bodies typical of the other centers. The developed ore extends from the bottom of the Escabrosa to the bottom of the Naco, a total thickness of over 700 feet. In one small outlying center the ore is confined to the top 400 feet of the Cambrian limestone.

The ground-water table west of Sacramento Hill inclines southeastward from an altitude of 5,000 feet (300 feet below the surface) at the ore outcrop to 4,350 feet at the Lowell mine, a mile to the southeast, a drop of 650 feet. East of Sacramento Hill the table is virtually level at an altitude of 4,300 to 4,350 feet. West of Sacramento Hill oxidation is essentially confined to the ground above the water table, whereas east of Sacramento Hill it is erratic and extends in deep hollows and channels to a maximum depth of 1,200 feet below the water table. The deep oxidized channels are probably due to deeper water tables established in the past, when the bordering intermontane plains were less filled by debris.

Ajo district[7]

By James Gilluly
United States Geological Survey, Washington

Geography

The Ajo copper district is in southern Arizona, in Pima County, about 43 miles south of Gila Bend, on the Southern Pacific Railroad, and 125 miles west

[7] Published by permission of the Director, U. S. Geological Survey.

of Tucson. It is in the extremely arid section of the State, with rainfall averaging less than 10 inches a year.

The district lies in the low desert plains, at altitudes ranging between 1,700 and 2,500 feet above the sea. The topography is hilly but not extremely rugged, with rather steep-sided hills rising abruptly above wide sloping pediments that merge into the alluvial intermontane plains.

History and production

Although the occurrence of copper at Ajo was established at least as early as 1750, it first came to the attention of English-speaking Americans in the days of the California gold rush of 1849. The first locations were made just after the Gadsden Purchase transferred the land to the jurisdiction of the United States, but the early attempts at exploitation were unsuccessful owing to the low grade of the ore, the difficulty of water supply, and the extremely costly transportation. A renewed attempt to develop the deposits was made in 1894, but it too was ephemeral.

At the beginning of the present century the brilliant success of the Utah Copper Co. at Bingham inspired much greater interest in the disseminated copper ores. Considerable promotion work was done at Ajo but little real development. Active work ceased with the panic of 1907 and left the district undeveloped beyond a few shallow prospecting shafts. At this time most of the mineralized area was held by the New Cornelia Copper Co. and the Rendall Ore Reduction Co. Both these companies enlisted sufficient capital to enable them to drill their holdings in 1909 and 1910, but the low tenor of the ore and the difficulty of concentrating the oxidized ore led to discouragement.

The active and successful development of the great deposit began in the fall of 1911, when the Calumet & Arizona Mining Co., of Bisbee, under the leadership of John C. Greenway, general manager, took an option on all the available stock of the New Cornelia Copper Co., reorganized the company under the same name, and began drilling to test the property. Test pits were later sunk and connecting drifts run to check the inferences from the drilling, with the resulting demonstration that a low-grade copper deposit existed with a surface exposure of over 100 acres and a maximum depth of over 1,000 feet.

The Rendall Co. was taken over about this time by a syndicate under the name "Ajo Consolidated Copper Co.," and a smaller group of claims (Childs) was optioned by the United States Smelting, Refining & Mining Co. but later abandoned after test. The Ajo Consolidated Copper Co. continued development of its property by diamond drilling and underground work until, in 1917, it was taken over by the New Cornelia. It has since proved to contain some of the richest ore in the deposit.

The successful exploitation of the deposit hinged upon development of a leaching process for the carbonate ores. Experiments in this direction were begun by the New Cornelia Co. in 1912 and continued until January, 1916, when the process had been so far developed that construction of a leaching plant was begun. The railroad from Gila Bend to Ajo was completed in 1915, and shipments of high-grade ores were made throughout 1916. An ample water supply was developed at the "water mine," about 600 feet deep, 7 miles north of Ajo; a town site was laid out; and a 5,000-ton crushing, leaching, and electrolytic precipitation plant was completed by May, 1917, when production in a large way began. In 1919 experiments in concentrating the underlying sulphide ores were begun, but the oxidized ores were the sole source of copper until 1924, when, a 5,000-ton concentrator having been built, production began from the sulphides. In 1930, most of the oxidized ore having been exhausted, the leaching plant was closed. In the meantime, in 1928 and 1929, the sulphide concentrator was enlarged to a present capacity of 16,000 tons a day. Relatively minor changes would increase the capacity to 20,000 tons.

In 1929 the New Cornelia Copper Co. was absorbed by the Calumet & Arizona Mining Co., and in 1931 this company was in turn consolidated with the Phelps Dodge Corporation. Since October, 1931, the property has been operated as the New Cornelia branch of the Phelps Dodge Corporation.

The production of copper prior to 1917 was probably less than 650,000 pounds. The production from 1917 to 1931, both inclusive, was about 763,000,000 pounds. Although copper is overwhelmingly the most valuable product, gold and silver recovered with it in the sulphide ores have netted about 5/6 cent per pound of copper. The developed reserves of the deposit are adequate for a life of 30 or 40 years at a rate of production in excess of 50,000,000 pounds a year.

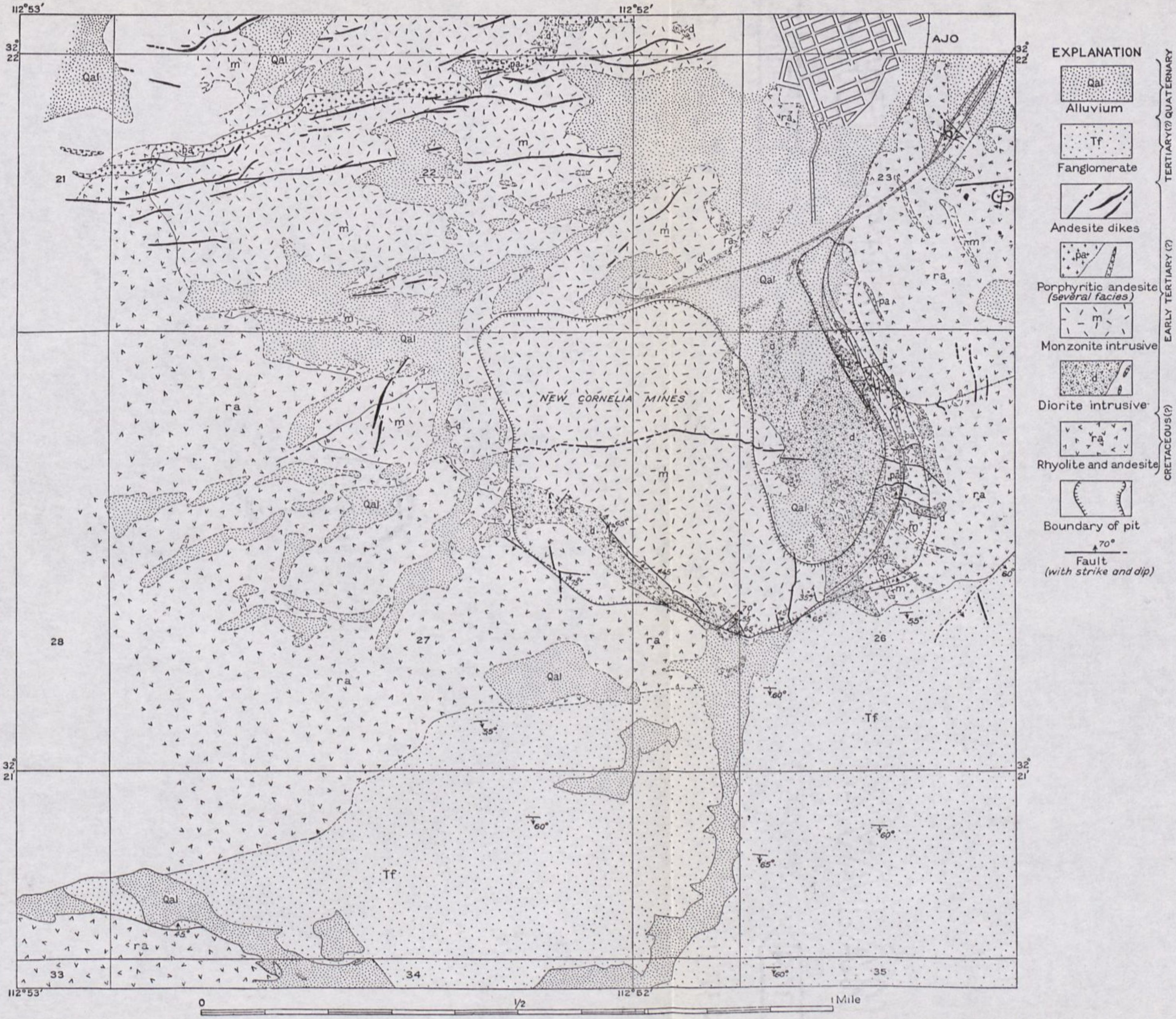
Geology

The oldest rocks in the immediate vicinity of the Ajo ore body (see pl. 14) are a series of lavas and associated tuffs, chiefly keratophyres and quartz keratophyres (locally called "rhyolites"), with subordinate andesite. It is possible that the keratophyric rocks were originally less sodic and owe their present chemical composition to later albitization.

The attitude of these volcanic rocks is uncertain, for although structures resembling flow phenomena are widespread they are of such diverse orientations, even on the same outcrop, as to preclude any confident deductions as to the original surfaces of the flows.

Into this volcanic series was intruded a composite wide dikelike body or elongated stock consisting of an external discontinuous shell of quartz dioritic composition as much as 1,000 feet wide but commonly much narrower or wholly lacking and a dominantly larger core of porphyritic quartz monzonite. The present surface outcrop of this intrusive mass is roughly wedge-shaped, with the point, in which practically all the known ore is concentrated, projecting toward the southeast. The northern and northeastern limits are obscured by alluvium. As now exposed it is about 2 miles long and a mile wide at the north end. At the south end the monzonite has been found by diamond drilling to extend at least half a mile south of its surface limit in that direction.

The southeastern tip of the quartz monzonite (as exposed on the surface) and the closely associated volcanic rocks are the host rocks of the ore deposit. The intrusive contact dips steeply south at the south end of the ore body (see fig. 20), and it is reported (28) that "rhyolite" occurred on top of some of the hills, since removed in mining, so that it is likely that the roof of country rock has



GEOLOGIC MAP OF THE VICINITY OF THE NEW CORNELIA COPPER DEPOSIT, AJO, ARIZONA

only recently been eroded from this part of the intrusive. Inasmuch as diamond drilling has demonstrated that the intrusive mass is relatively thin, with "rhyolite" beneath, it may be that the body as a whole is tabular, in a general way parallel to this contact.

The tip of the monzonite and the adjoining volcanic rocks are truncated at the south by a clean-cut, rather even erosion surface on which rests a great thickness of fanglomerate with intercalated volcanic rocks, now dipping 60° or so to the south. The fanglomerate contains boulders of mineralized monzonite, diorite, and numerous rocks of exotic source, such as schists, coarse granite gneiss, and fossiliferous Carboniferous limestone, none of which are known to be of local derivation.

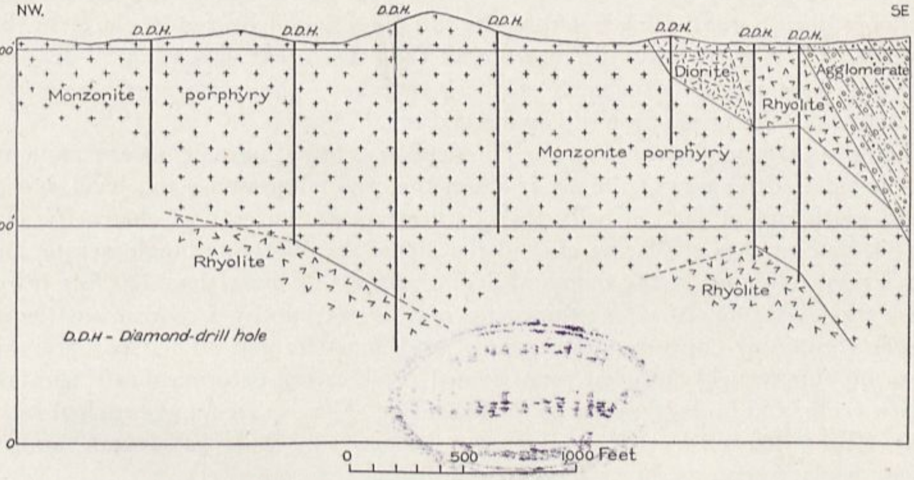


FIGURE 20.—Geologic section through Ajo ore body, Ajo district, Arizona. (After Ingham and Barr (29).)

The ore body is almost wholly in the monzonite, although volcanic rocks just to the southwest and southeast are also considerably mineralized. It is crudely elliptical in shape, about 3,600 feet long by 2,500 feet across. Its average thickness (29) is 425 feet, and the maximum about 1,000 feet. Most of the ore is in a rather flat lens, with a deeper northwestward-trending keel, but at the south end a tongue dips steeply southward to great depths.

The primary ore consists chiefly of chalcopyrite, with bornite and a little pyrite. The gangue is quartz and orthoclase, and the sulphides are distributed both in veinlets and in discrete grains through the altered monzonite. A little tennantite, considerable magnetite and specularite, and a little sphalerite and molybdenite also accompany the ore. The rock is highly orthoclasized, really pegmatized, along two main north-northwesterly zones, and the richest ore accompanies this more intensely altered rock. Chlorite and sericite after plagioclase are widespread, but the rock contains so much orthoclase and quartz that it is extremely hard and resembles fresh rock physically, contrasting markedly with the soft, chalky-appearing ores of most of the "porphyry coppers."

The ore body was oxidized to a surprisingly level plane near the present water table, at an altitude of about 1,800 feet. There were local variations of as much as 50 feet, but for the most part the transition from sulphide to the oxidized zone was about as sharp as could be mined by steam shovel and was at nearly the same altitude beneath hill and valley. The depth of oxidized ore thus ranged from 20 to 190 feet, with an average of about 55 feet (29). The minerals of the oxidized ore were malachite with a little azurite, cuprite, tenorite, chrysocolla, hematite, and limonite. A little chalcocite occurs close beneath the bottom of the oxidized zone.

The fact that in most of the ore body the tenor of ore was essentially the same in oxidized and subjacent sulphide ore seems to show, in connection with the rather insignificant quantity of chalcocite, that there was little migration of copper during weathering but that the sulphides were oxidized in place. In this respect the Ajo ore body differs from all the other great disseminated deposits of the Southwest, for in each of these supergene chalcocite enrichment was essential to the production of commercial ore.

The supergene chalcocite of the Ajo deposit is found in insignificant amounts over most of the area of the pit at about the original ground-water level, but at the south end of the ore body there is a crescentic outcrop of chalcocitic ore. This zone pitches 60° S., parallel to the dip of the overlying fanglomerate, and has been followed by the diamond drill to depths of more than 200 feet below sea level. (See fig. 20.) This chalcocite zone is overlain by a reddish weathered zone containing cuprite, native copper, and hematite and obviously represents an old supergenely enriched zone formed prior to the deformation of the fanglomerate, and probably prior to its deposition. The oxidized and enriched zones have been deformed in this region and dislocated by faults of several hundred feet displacement, as shown by diamond drilling.

The existence of this zone, in which ore containing 3 to 4 percent of copper is common, indicates that the absence of enrichment in the present cycle of erosion may not be due, as has been commonly suggested, to the small amount of pyrite in the ore. It is possible that climatic factors may be more important in this connection, although it is possible that the pyrite factor may be dominant after all—long-continued erosion, depression of the water table, and consequent weathering of much larger quantities of pyrite than were available during the present cycle being necessary to produce the older chalcocite enrichment.

The close association of the ore deposition with the pegmatization of the quartz monzonite porphyry is sufficiently indicative, in conjunction with the content of magnetite and specular hematite, of its igneous origin. The emplacement was largely effected by metasomatic processes, guided by the widespread fissuring along dominantly north-northwest lines.

The regional geologic setting of the Ajo deposit is not yet well enough known to furnish clear-cut data as to its age. No fossiliferous rocks are involved in the nearby structures. The present erosion surface has been masked by volcanic flows, now largely removed. This surface is carved across the steeply tilted fanglomerate, and that in turn rests on a presumably deeply eroded surface of mineralized monzonite. Thus if the deposit is Tertiary, as has been suggested, its formation has been succeeded by a long and rather involved history. On the other hand, intense contact metamorphism of Carboniferous (?) limestones in the Growler Mountains, to the south, may indicate that the major intrusives were post-Carboniferous. As far as direct data go, then, nothing can yet be said with certainty as to its age—the probabilities lie between Permian and early Tertiary.

Mining methods

The deposit is mined by the open-cut method, with steam shovels operating on benches at vertical intervals of 30 feet. The present outline of the pit and its relation to the ore body are shown in plate 14. Inasmuch as the oxidized part of the ore body was practically as productive as the sulphide part, there was here no stripping problem of the sort confronting most of the disseminated deposits of the Southwest. To January, 1931, less than 7,000,000 tons of waste had been moved in the mining of 32,400,000 tons of ore, a ratio of 0.21 ton of waste to 1 ton of ore. Much of this waste occurred within the ore body and was not overburden. However, as the depth of the pit increases a larger proportion of waste will have to be moved in order to maintain a safe angle of slope.

Minor copper-producing districts

The Big Bug district, 15 miles southeast of Prescott, in Yavapai County, had produced up to 1930 at least 60,000,000 pounds of copper, chiefly from deposits formed by impregnations of silicified schist (4). The nearby Peck district had produced between 12,000,000 and 15,000,000 pounds of copper, largely from similar deposits (4).

The Pima district, in the Sierrita Mountains, about 20 miles south-southwest of Tucson, had produced to the end of 1930 over 35,000,000 pounds of copper, largely from contact-metamorphic deposits in limestone (30).

The Turquoise (Courtland-Gleeson) district, in the Dragoon Mountains, about 18 miles north-northeast of Bisbee, has produced probably 50,000,000 pounds of copper, chiefly from replacement deposits in Paleozoic limestone near monzonite intrusions (31).

The Silver Bell district, about 35 miles northwest of Tucson, has produced probably more than 70,000,000 pounds of copper from contact-metamorphic deposits in limestone (32).

The Patagonia district, about 60 miles south-southeast of Tucson, had to the end of 1930 produced at least 8,000,000 pounds of copper and possibly considerably more. The principal deposits are replacement ores in limestone near a quartz monzonite intrusive (33).

The Bentley (Grand Gulch) district, in Mohave County, has produced over 8,000,000 pounds of copper from replacement deposits in limestone (34).

The Planet (Swansea) district, in Yuma County, produced over 28,000,000 pounds of copper between 1909 and 1930 from replacement deposits in limestone (35).

The Copper Basin district, in Yavapai County, has produced about 10,000,000 pounds of copper from disseminated deposits in granitic rocks (32).

The Agua Fria district, Yavapai County, has produced over 12,000,000 pounds of copper from siliceous replacement deposits in schists (3, pp. 146–149).

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The Shasta County copper belt, California

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Introduction

Geography.—Most of the Shasta County copper district lies a few miles west of the Sacramento River (see fig. 21), at distances of 5 to 15 miles north of Redding. The main north-south line of the Southern Pacific Railroad follows the Sacramento River Canyon above Redding, and several stations and small towns on the railroad formerly served the copper mines. The population of these towns has now greatly declined. The topography is very rugged, with steep slopes rising from the river at an altitude of 500 feet to peaks at 4,500 feet. The climate is mild, with long, dry summers, during which the temperature sometimes reaches 110° F. In the winter several feet of snow is common at the mines, but very little falls at river level, where freezing temperatures are only occasional.

History and production.—The deposits have produced 684,000,000 pounds of copper, which was sold for $110,000,000. Considerable gold and silver were produced from the same ores, but Shasta County has produced these metals from ores other than copper ores, and segregated figures are not available. The copper production of the district was at its height from 1898 to 1919. Except for a spurt in 1924, it then gradually declined to practically nothing at present (1933). The Shasta County deposits have, during recent years, been much less productive than those of Plumas County, particularly the Walker mine. The smelters of Shasta County have all been dismantled, and ore must now be shipped either as raw ore or flotation concentrate, requiring a minimum price of 12 cents a pound for copper to cover costs. Metal production in the district is now confined largely to gold (3) and a little silver, which are extracted from the gossan above the flat-lying bodies of sulphide. One mine is equipped to produce 600 tons a day of pyrite for the manufacture of sulphuric acid, and a little copper is derived from residues, also a little from mine water.

Geology

The Klamath Mountains, in which these deposits are located, are similar geologically to the Sierra Nevada, of which they are perhaps a part, but are isolated from it by the sediments of the upper Sacramento Valley and the young lavas of the Lassen Peak region. Within a radius of 50 miles of the copper belt an unusually complete geologic column is available for study. It includes very old schists, of unknown age, possibly Archean; a series of pre-Devonian lava flows; Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary sediments; a series of igneous intrusives ranging from serpentine to granodiorite; and finally a series of Tertiary and Quaternary lava flows. (See fig. 22.)

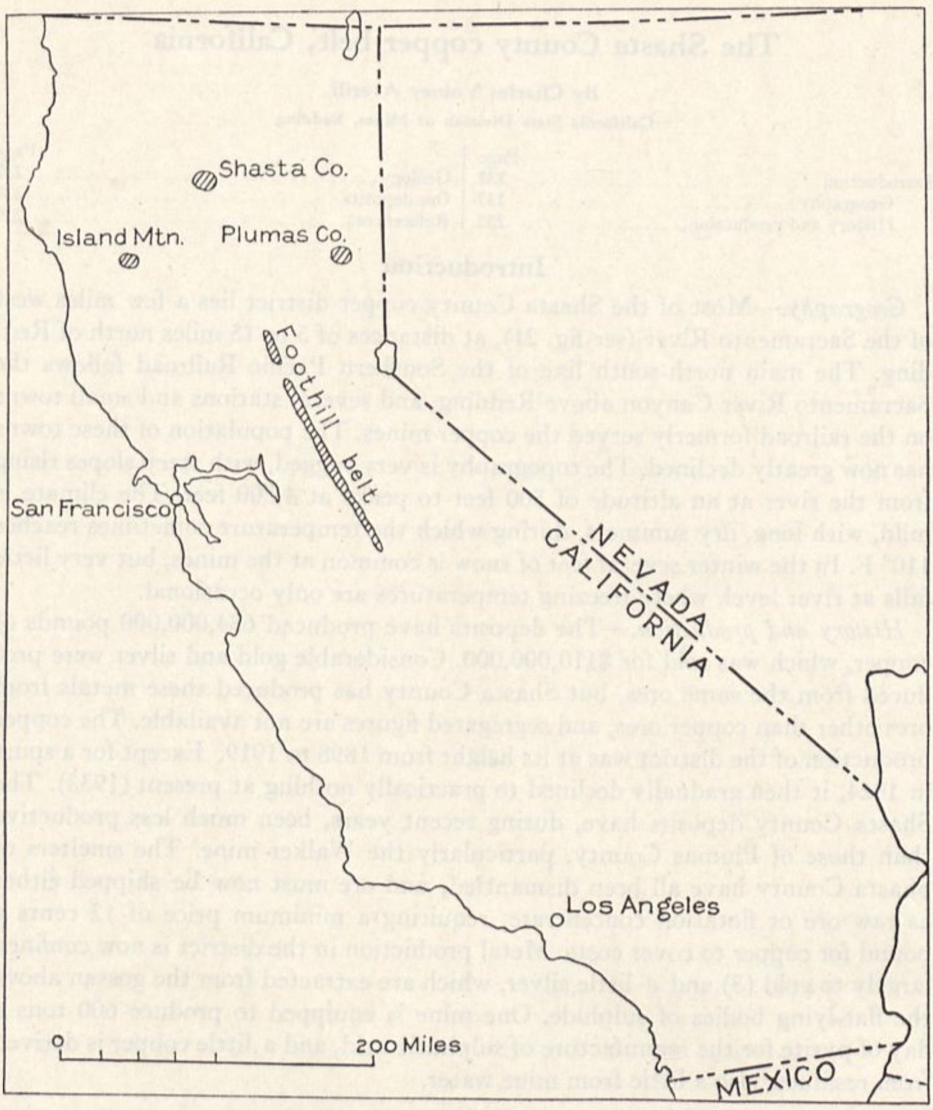

FIGURE 21.—Map of California, showing location of copper-producing areas.

The formation of outstanding interest in the copper belt is the alaskite porphyry (4, 5)—Balaklala rhyolite (6), granite porphyry (1)—a silica-rich albite granite porphyry. Typically it is a greenish-gray rock of very fine grain. The groundmass is a microgranular mixture of quartz and feldspar, and the phenocrysts are usually minute also but in places reach a diameter of a quarter of an inch. The phenocrysts consist of quartz and albite, rarely oligoclase-albite; and there are small grains of magnetite, chlorite, and epidote, possibly derived from original biotite; also accessory apatite, titanite, and zircon. There has been some disagreement as to whether the alaskite porphyry is one formation or a series.

It is apparently a complicated series of intrusions, but whether these are distinct enough to be mapped separately is uncertain. The rock intrudes the pre-Devonian Copley meta-andesite, the shales of the Kennett formation (Devonian), the shales of the Bragdon formation (Carboniferous), and the shales and tuffs of the Pit formation (Triassic). The alaskite porphyry must be as young as late Triassic, and its intrusion was probably contemporaneous with the late Jurassic mountain-making in the Sierra Nevada, 100 miles to the southeast.

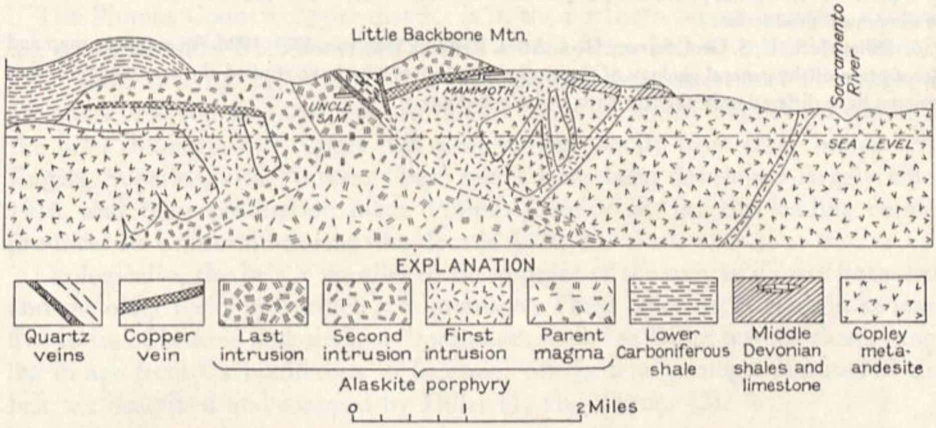

FIGURE 22.—Idealized vertical section of part of Shasta County copper belt, California, looking north. Contacts between various intrusions of alaskite porphyry are generalized and are intended to show complexity of the intrusion.

Ore deposits

The copper deposits form large flat-lying masses of pyritic ore, with maximum dimensions of 1,200 feet in length, 300 feet in width, and 300 feet in thickness. The Iron Mountain ore body, before a great part of it was converted into gossan, is thought to have contained 20,000,000 tons (5). These deposits are replacement deposits in the alaskite porphyry, probably following zones of shattering (5). The ore minerals are pyrite, chalcopyrite, sphalerite, and small amounts of galena, bornite, and chalcocite. The grade of these heavy sulphide ores was roughly 3 or 3½ percent of copper, and $1.50 to $2 a ton in gold and silver. Ore showing sulphide enrichment has been found in some of the mines, but it is not important. Recent copper production has come from small quartz veins carrying chalcopyrite, which dip at steep angles beneath the tabular masses of pyritic ore. This ore is amenable to flotation concentration, and the future copper production of the district seems likely to come from the siliceous ores.

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The Plumas County copper belt, California

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The Plumas County copper district is in the northern Sierra Nevada, extending southeastward from southern Lassen County in a belt 45 miles long and 20 miles wide. (See fig. 21, p. 238.) It is near the easternmost crest of the range, at altitudes of 4,500 to 7,000 feet. Although there are many copper prospects in the belt, the output of copper has come almost wholly from three mines—the Engels, Superior, and Walker. These mines have been developed largely since 1916, and their production made Plumas County by far the leading copper producer in California during the decade 1920–30.

Geologically, the belt is parallel to the contact of the quartz diorite batholith and the older rocks into which it is intrusive. These older rocks contain at least five series of bedded andesites, or "meta-andesites," as Diller termed them, ranging in age from Carboniferous to Jurassic. The general geologic features of the belt are described and mapped by Diller (1) and Turner (2).

Engels copper deposits

The outcrop of the Engels copper deposits (3, 4) is at an altitude of 5,400 feet, on the ridge bordering the east side of Lights Creek. The Engels Copper Mining Co. began operations in 1914, and after the standard-gage railroad 22 miles long was built in 1917, connecting the lower camp with the main line of the Western Pacific Railroad, the property was extensively developed and became one of the leading producers in California. To the end of 1927 the Engels and Superior mines yielded 133,770,600 pounds of copper. In July, 1930, the two mines were closed down indefinitely. The Engels mine was worked chiefly through adit 10, which is 8,400 feet long and cuts the ore zone 1,200 feet below the outcrop.

The oldest rocks in the Engels area consist of andesite and keratophyre lavas. Near the mine they have been drastically altered by contact metamorphism. Some of the andesites have been changed to biotite-hypersthene hornfels.

Intrusive into the ancient lavas are a series of plutonic rocks, the oldest of which is a hornblende-bytownite gabbro. This gabbro is of much interest, inasmuch as it is one of the principal rocks in the mine. The next younger intrusive is quartz diorite, which has formed extensive shatter breccias with the andesites and other pre-plutonic rocks, well exposed on level 10 and lower workings. Some of these intrusion-contact breccias became mineralized and constitute valuable ore. Still younger is a fine-grained quartz monzonite, which constitutes the country rock at the Superior mine, and youngest of all is a coarse white alaskitic granite.

The ore bodies occur at the contacts of the gabbro and quartz diorite with roof pendants of the pre-plutonic rocks. Ore occurs not only in the gabbro but also in the quartz diorite that is intrusive into the gabbro, and it occurs in the adjacent roof-pendant material, which is mainly hornfelsed andesite but includes some salic rocks and quartzose hornfels.

There are at least four ore bodies—(*a*) the main ore body, which has yielded the bulk of the ore and is the one to which most of the previously published descriptions pertain (5, 6, 7, 8, 9); (*b*) the "02" ore body, in which the ore persists deepest; (*c*) the "08," which is 300 feet in the hanging wall of the main ore body; (*d*) the ore body known as the "A stope." They all dip steeply. The "02" is an irregular pipe in quartz diorite which was worked to a depth of 1,300 feet below the outcrop and in which the mineralization, as shown by diamond drilling, persisted downward at least another 500 feet.

The metallic minerals are chalcopyrite, bornite, ilmenite, and magnetite. The ore has a wide range in appearance, from black to white, according to the nature of the host rock, whether it is gabbro, or quartz diorite, or hornfelsed andesite, or keratophyre, or quartzose hornfels.

The alterations effected during the introduction of the oxides and sulphides were exceedingly thorough: in the hornblende gabbro they comprised actinolitization of the hornblende, biotitization, and the recrystallization of the large pyrogenic bytownite (An_{80}) and of the labradorite (An_{55}) of the quartz diorite into fine-grained mosaics of andesine. The metallic minerals were then deposited, chiefly by replacement of the newly formed andesine and biotite. The deposition of the bornite and chalcopyrite lasted longer than that of the magnetite and ilmenite, but probably only slightly longer, for the sulphides rarely fill fissures in the oxides.

After the main deposition of the oxides and sulphides, lower-temperature ("hydrothermal") alteration affected the ore bodies locally. Chlorite, stilbite, analcite, and siderite were formed. Stilbite was the mineral most abundantly formed during this stage, and probably some hypogene chalcocite was deposited.

On the basis of the exsolved disks of hematite that occur in the ilmenite and the experimental study by Ramdohr of the homogenization of ilmenite containing such exsolved lamellae, it was originally thought that the temperature of deposition of the ilmenite was about 700° C. (3, pp. 28–29). Greig, however, has shown that Ramdohr's experimental work is inconclusive (10); possibly it shows that the temperature of deposition of the ilmenite was as low as 500°. From the work of Schwartz (11) it must be concluded that the bornite and chalcopyrite have been deposited below 475°, for mixtures of bornite and chalcopyrite heated above 475° form solid solutions, and these solid solutions readily unmix to form crystallographic intergrowths. Such crystallographic intergrowths are conspicuously absent from the Engels deposits. Now, ilmenite is sensitive to autometamorphic, pneumatolytic, and hydrothermal agencies, yielding magnetite and rutile (12). Furthermore, magnetite readily changes to an iron sulphide under hydrothermal conditions in which sulphide ions are present. It is therefore reasonable to conclude that at the time of maximum deposition of the bornite and chalcopyrite conditions had not shifted far from the oxide-forming stage to the sulphide-forming stage. In short, the conditions during which most of the copper ore was formed at Engels were essentially like those that prevail during the deposition of the pyrometasomatic copper ores.

Superior mine

The Superior mine, owned by the Engels Copper Mining Co., is on the east side of Lights Canyon, 1 mile west of the Engels mine. It is just below the town of Engelmine, the terminus of the branch line from Paxton, on the Western Pacific Railroad.

The country rock is a uniform fine-grained quartz monzonite. It is cut by various dikes, including albitite, aplite, and albite granite porphyry. Most prominent in the mine workings are a series of black microcrystalline dikes, which are sparsely plagiophyric and are best termed "malchites."

There are six parallel veins, dipping on the average 40° E., distributed through a belt 1,800 feet wide. The A vein was the most notable; although a normal tabular vein in depth, near the surface it had expanded into a large stockwork. The metallic minerals are magnetite, chalcopyrite, bornite, and minor pyrite; the gangue minerals are chiefly biotite and tourmaline, forming a black aphanitic matrix. The wall rocks are extensively tourmalinized, but adjacent to some of the veins they grade from tourmalinized to epidotized rock. Stilbite in perfectly formed rosettes an inch or so in diameter occurs in some of the ore and was obviously the last mineral to form.

The malchite dikes near the veins have been thoroughly altered by the ore-forming solutions, being in fact masses of alteration products—biotite, actinolite, epidote, chlorite, and sporadic chalcopyrite—and were therefore injected before the ores were formed.

Walker mine

The Walker mine marks the south end of the Plumas copper belt. It is at an altitude of 6,100 feet, 27 miles from Portola, the nearest town on the Western Pacific Railroad. Because of the altitude the mine is snow-bound during part of the year, and an aerial tramway to the railroad at Spring Garden, a distance of 9 miles, was therefore built in 1920. The concentrate is transported to the railroad continuously throughout the year over this tramway.

The mine is worked through a long adit equipped with an electric tramway. The ore is milled in a plant having a daily capacity of 1,700 tons. The ore averages 1.7 percent of copper, and from it is produced by flotation a concentrate containing 24 percent copper and 9.9 ounces of silver and 0.49 ounce of gold to the ton (13). From the beginning of operations in 1916 to the end of 1930 more than 100,000,000 pounds of copper had been produced. A peak was reached in 1930, when 14,654,793 pounds was produced, and the value of the output, $1,921,355, "was the largest for recovered metals for any single mining property or district in California" in that year (14).

The ore bodies occur near the contact of quartz diorite with highly metamorphic rocks, which from the fossils found in them by Turner (15) are known to be of Carboniferous age. Andalusite-garnet rocks and cordierite hornfels are the principal types. At the immediate contact with the quartz diorite the invaded rocks have been very notably tourmalinized.

At least four ore bodies—the South, Central, North, and Piute—occur in a linear belt several thousand feet long. The ore bodies are large, the North ore body, for example, being 1,600 feet long on the 700 level and as much as 125 feet wide. They dip steeply eastward. No ore occurs in the quartz diorite, but the ore belt extends northward away from the contact, and all ore is enclosed in biotitic, garnetiferous, and andalusitic rocks, which have been powerfully altered by the ore-forming solutions. The garnet has been fissured and replaced by chalcopyrite and chlorite, and the andalusite replaced by muscovite.

The gangue mineral is predominantly quartz, ranging from fine-grained to coarse, glassy—very unlike the gold-bearing quartz common throughout the Sierra Nevada. Barite occurs sporadically. The metallic minerals are chiefly chalcopyrite with minor pyrrhotite and cubanite, but locally the ore contains much magnetite. Pyrite is rare. Tourmaline and actinolite in places occur as veinlets cutting the quartz. It is clear, both megascopically and microscopically, that the quartz was formed first, was shattered later, and then the magnetite, followed by tourmaline, actinolite, and the sulphides, were introduced.

Conclusions

All three of the principal deposits of the Plumas copper belt—Engels, Superior, and Walker—are magnetite-bearing copper deposits. Actinolitization has occurred at all three, and tourmalinization at two. Ilmenite, however, is abundant at Engels but does not occur at the others. The notable difference in the geologic environment is the occurrence of the hornblende gabbro at Engels, and this suggests that the titanium in the ilmenite of the Engels ore was obtained from the gabbro by the passage of the ore-forming solutions through it. An analogy is the occurrence of the chromiferous mica mariposite in the gold veins of the Sierra Nevada only in proximity to or where they cut the chromiferous rocks, serpentine and peridotite. All three deposits of the Plumas belt are of high-temperature origin: at Engels conditions during the maximum deposition of copper sulphides approximated those prevailing during contact metamorphism; at Superior the temperatures were somewhat lower; and at the Walker mine, as indicated by the presence of cubanite, they were near 400° C.

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The foothill copper belt of California

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Introduction

The copper deposits of the foothill belt of California are of three types—massive lenticular pyrrhotitic copper deposits, containing zinc and gold; massive lenticular pyritic copper-lead-zinc deposits, containing gold and silver; tabular pyritic copper-lead-zinc-gold-silver deposits. All three types were formed by the replacement of schistose effusive and intrusive members of the "bedrock complex" of the foothill region of the Sierra Nevada.

Selective replacement of a favorable band or layer of schist results in tabular ore bodies, and a less selective replacement of more homogeneous schist produces large lenses of cupriferous pyrite and pyrrhotite. The former may be classified as a variety of the "fahlband" type of deposit.

The foothill copper belt was discovered in the early sixties, and by 1865 the Spenceville mine, in Eldorado County; the Cosumnes and Ione mines, in Amador County; and the Campo Seco mine, Copperopolis group, and Napoleon property, in Calaveras County, had produced large quantities of copper, and long stretches of the so-called "lodes" were located.

Deeper developments bottomed several of the large pyritic lenses, the heavy zinc content of all the mines except Copperopolis raised metallurgical difficulties, and the active development of the copper deposits in Shasta County in 1906 diverted attention from the foothill belt. The Dairy Farm mine, however, continued to produce low-grade cupriferous pyrite until 1918. The extraordinary pencil-shaped ore shoot of the Campo Seco mine was exhausted at the depth of about 3,000 feet in 1920 (fig. 23). Finally the Copperopolis mine shut down in 1930, when the price of copper declined.

The mines and prospects of the central portion of the belt are alined with the outcrops of favorable schist bands. The individual lodes or belts range from 1 mile to 20 or 30 miles in extent. These belts occur en échelon and are shown in plate 15.

Geology

Detailed investigations have been limited to the pyritic ores of the main mineral belts from Valley View to Copperopolis.

The bedrocks are chiefly metamorphosed volcanic rocks designated in the United States Geological Survey folios "amphibolite," "meta-andesite," and "greenstone." The principal rocks are meta-andesite and metarhyolite. These are cut by irregular intrusives, chiefly serpentine, gabbro, and pyroxenite, and by sills parallel to the layering of the metavolcanic rocks. These sills can be separated from the flow rocks only by detailed work. The metavolcanic rocks occur chiefly between the Calaveras (Carboniferous) and Mariposa (Jurassic) slates and also interstratified with the Mariposa. Schistosity is parallel to the layering of the volcanic rocks. The strike is northwest, and the dip is 45°–90° E.

The schistose formations constitute a synclinal block, closely compressed into secondary isoclinal folds and bounded on the north, east, and south by the Sierra Nevada batholith, and interrupted on the west in the vicinity of Ophir by cupola stocks which are offshoots of the batholith. (See pl. 15.)

Lodes and shoots.—The ore-bearing members have been mineralized into quartz-sericite-pyrite schist (mineralized phase of metarhyolite) and the more basic rocks into chlorite-epidote-pyrite schist. These mineralized layers are called lodes. Metallization and the resulting introduction of copper, zinc, lead, gold, and silver was far more restricted than mineralization, giving rise to flat lenses or steeply plunging narrow ore shoots. (See fig. 23.)

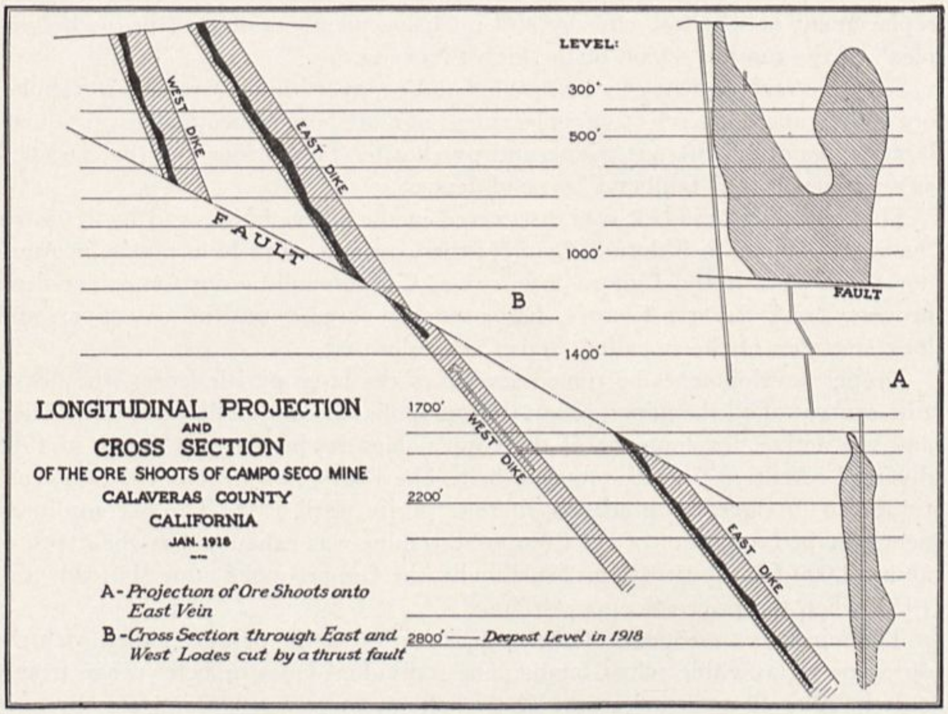
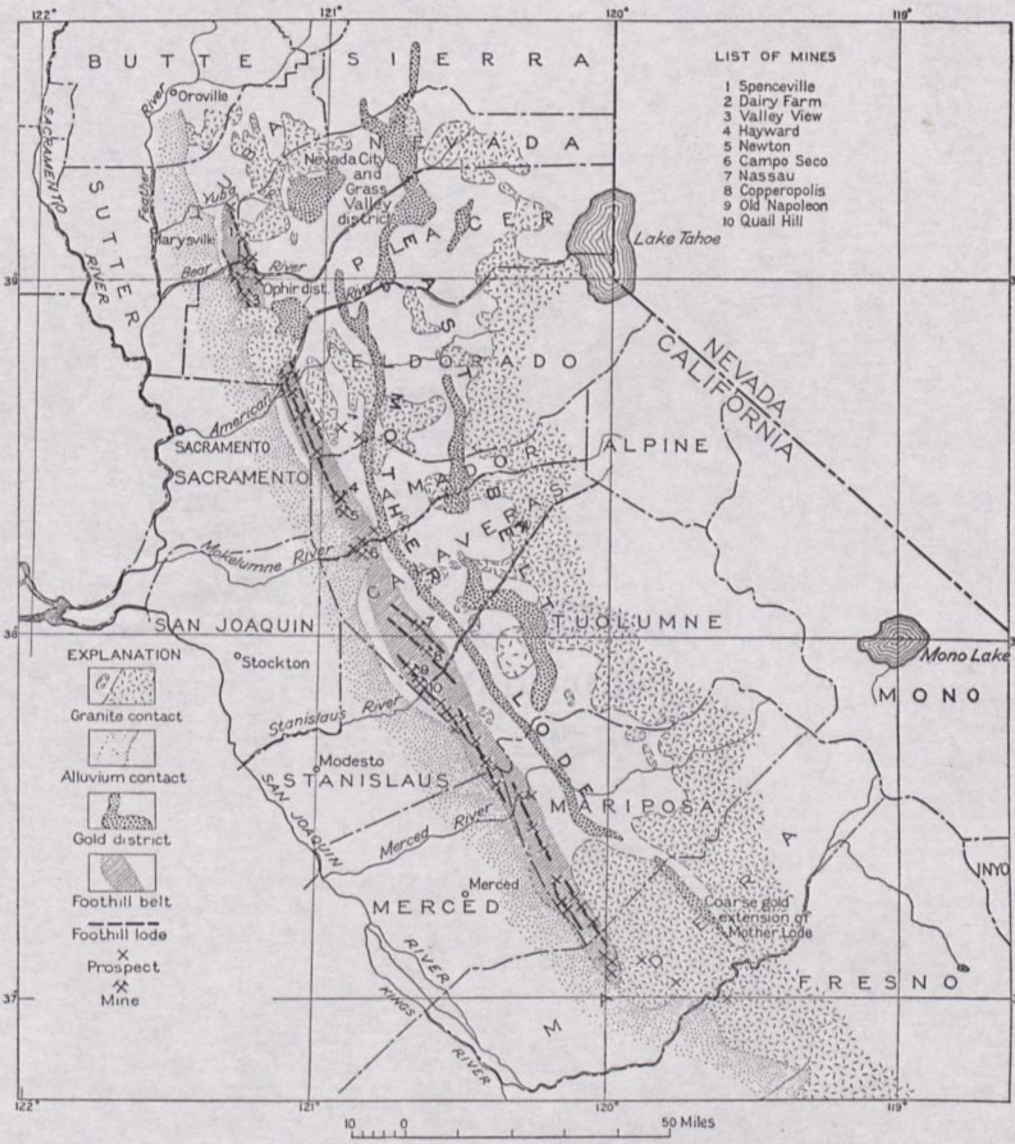


FIGURE 23.

Outcrops.—The mineralized bands are marked by gossan outcrops and exposures of leached friable schist locally stained with copper or iron salts. At a few localities soluble salts of copper, zinc, and iron occur as an efflorescence on the outcrops of the ore-bearing schist. Some of these gossans are now (1935) being worked as low-grade gold deposits.

The ore is not confined to any one variety of schist, although it commonly occurs in mineralized metarhyolite in the central portion of the region.

Mineralogy.—All the tabular complex lead-zinc-copper ore deposits of the central portion of the foothill belt are very similar in occurrence, mineral association, and accompanying rock alteration, with the one exception of Copperopolis.



MAP OF THE FOOTHILL COPPER BELT OF CALIFORNIA

Showing principal mines and prospects, the Sierra Nevada gold belt, the granite-schist contact, and the bedrock-alluvium contact.

XVI Int. Geol. Cong.

The ores are so much alike that if the specimens from the various mines were unlabeled, it would be difficult to identify their source.

The ore minerals of the tabular group are intricately intermixed pyrite, sphalerite, tetrahedrite (rare), chalcopyrite, bornite (rare), and galena. The more abundant minerals both include and are margined by the other minerals. "Mutual boundaries" are the rule. However, detailed study of extensive suites of thin sections and polished surfaces (see pls. 15A, 15B) has shown that mineral introduction was progressive and that the minerals were introduced in the order in which they are listed above. After extensive pyritization, subsequently introduced minerals partly or completely replaced the available residual gangue fragments. In complete replacement the replacing minerals appear as "inclusions." The contact between the older sulphides and the gangue was vulnerable to attack by the later minerals, and therefore marginal relations of the gangue sulphides around the older sulphides are common.

The massive pyritic lenses carry less sphalerite and chalcopyrite than the tabular deposits, galena is rare, and bornite and tetrahedrite are absent. The order of introduction was sphalerite, chalcopyrite, and galena.

In the few pyrrhotitic ore specimens examined sphalerite and pyrite are the only common accessory primary sulphides, and chalmersite was identified in the ore from the Dalton mine.

Selective replacement.—Selective replacement is shown by the preservation of the schistose layering in the banded ores. Even complete oxidation of massive banded ore did not efface the schistose textures. Complete solution and removal of the ore minerals left a porous siliceous skeletal mass of residual gangue fragments, which by its structure illustrates how solutions can penetrate massive ore along the contact between ore minerals and gangue residuals.

Sulphide enrichment.—In all three types of ores examined the effects of supergene enrichment can be distinguished from those of hypogene metallization. The supergene sulphides cut the hypogene ore minerals in sharp reticulated veinlets. A central core filled with soft powdery minerals represents the original crack, and the secondary sulphides have eaten out into the various primary minerals. The secondary sulphides are white chalcocite, blue chalcocite (submicroscopic mixture of chalcocite and covellite), covellite, and rarely chalcopyrite.

Nowhere was enriched ore encountered more than 50 feet below the water table. The enrichment materially increased the copper tenor of the ore only rarely. The notion, therefore, that supergene enrichment produced the better-grade ore encountered in several of the mines within a few hundred feet of the surface is erroneous.

Structure of the ore shoots.—Space is not available to discuss the detailed geology of the mines examined or the structure and shape of the ore shoots. As an illustration, the pencil-shaped and faulted ore shoot of the Campo Seco mine is shown in figure 23. In spite of the high grade of this ore body and the great depth to which it was mined, the lode (quartz-pyrite-sericite schist) was not extensively explored on either side of the main ore shoot.

Origin of the deposits.—With the doubtful exception of pyrite accompanied by silicification, the sulphides were introduced after the metamorphism of the country rock.

The mineralization and metallization were not limited to the basic phases of the schists, as suggested by Lindgren, nor related to local intrusives, as has been common elsewhere. Like the gold mineralization of the Sierra Nevada, the copper mineralization of the foothill belt was later than the intrusion of the Sierra Nevada batholith and subsequent to the contact metamorphism connected therewith, contrary to Lindgren's conclusion that the copper mineralization was earlier than the gold mineralization and related to pre-batholithic basic intrusives. The extraordinary similarity of the foothill ores along a line parallel to the Mother Lode for over 100 miles and a regional variation in mineralization away from this line, toward the granite batholith, in a similar fashion to the gold deposits, indicate a similar genetic relation to the batholith.

The distribution of the principal groups of gold-quartz veins of the Sierra Nevada is shown in plate 15. The Mother Lode is predominantly mesothermal (formed at moderate temperature). The mineral association of the gold-bearing deposits exhibits a regional variation, changing to hypothermal types on the north, east, and south, toward the batholith. The East lode contains high-temperature minerals such as pyrrhotite, arsenopyrite, and magnetite, and some of the lodes are cut by dikes, which represent the end products of batholithic intrusion. Mineral association also indicates higher-temperature ore deposits to the north, toward Grass Valley, and to the south, in the contact-metamorphic schists caught up in the granite.

Similarly the foothill copper deposits exhibit a regional variation in mineral composition, with higher-temperature types toward and in the granite, where pyrrhotite takes the place of pyrite as the predominant sulphide.

The facts above set forth suggest that both the gold-quartz deposits of the Sierra Nevada and the pyrite and pyrrhotitic base-metal replacement deposits of the foothill belt are the results of a widespread regional mineralization which was an after-effect of the intrusion of the batholith.

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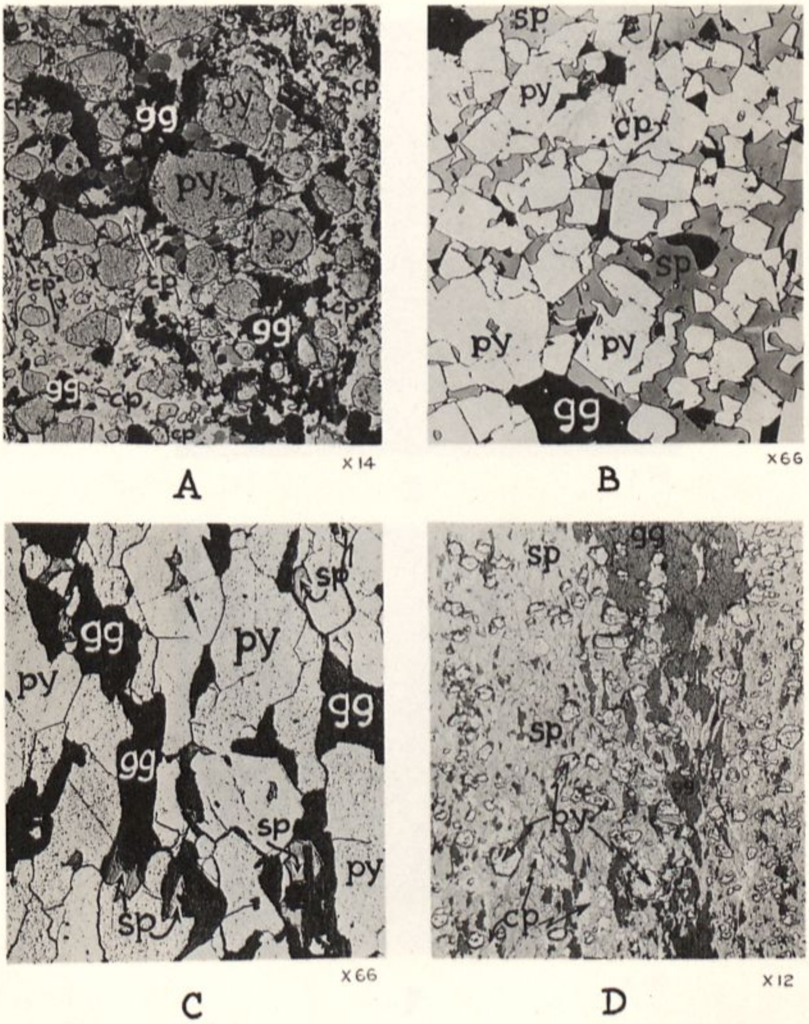


POLISHED SURFACES OF SPECIMENS FROM FOOTHILL COPPER BELT OF CALIFORNIA

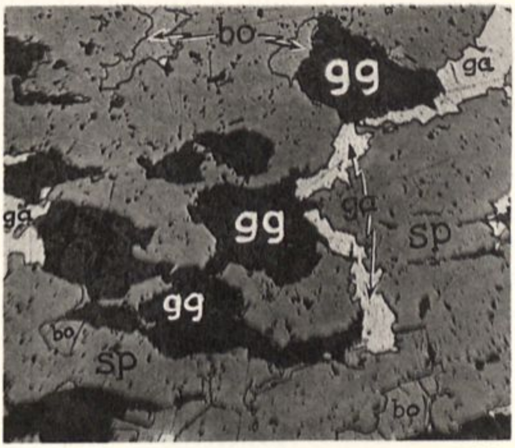
Py, Pyrite; cp, chalcopyrite; sp, sphalerite; gg, gangue.

A, Typical high-grade ore, Campo Seco mine, 2600 level. Pyrite cemented by chalcopyrite. Specks in chalcopyrite are bornite, tetrahedrite, galena, and sphalerite.

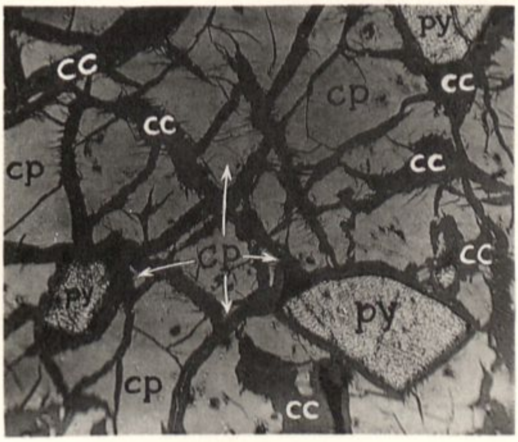
B, Low-grade massive pyritic ore, Dairy Farm mine. Pyrite cemented by sphalerite and chalcopyrite.

C, Dairy Farm mine. Schistose gangue in and between pyrite crystals replaced by sphalerite.

D, Pyritized schist (gg) replaced by chalcopyrite and sphalerite preserving schistose texture.



E



F

POLISHED SURFACES OF SPECIMENS FROM FOOTHILL COPPER BELT OF CALIFORNIA

E, Progressive replacement of gangue residuals, Campo Seco mine. The gangue (gg) is included in sphalerite (sp) and is selectively replaced by bornite (bo) and galena (ga).

F, Supergene enrichment, Dairy Farm mine. Blue chalcocite (cc) replaces chalcopyrite (cp). Shreds of chalcocite penetrate chalcopyrite along crystallographic directions. Py, Pyrite.

Copper in Trinity County, California[1]

By W. D. Johnston, Jr.
United States Geological Survey, Washington

The greater part of the copper produced in Trinity County has come from the Island Mountain mine, in the southwest corner, on the Northwestern Pacific Railroad. (See fig. 21.) Discovered in 1892, it has yielded 120,000 tons of ore up to the cessation of operations in 1930. A lenticular ore body enclosed in shales and sandstones carries copper and iron sulphides averaging 3 percent of copper, with 1½ ounces of silver and $2 in gold to the ton. The ore body is 90 to 100 feet wide and 420 feet long and has been followed to a depth of 145 feet.

There are several copper prospects in ores of basic rocks in the New River, Carrville, and Trinity Center districts, but their production is negligible.

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Copper-bearing ores of Colorado[1]

By W. S. Burbank

United States Geological Survey, Washington

San Juan Mountains

The San Juan Mountains of southwestern Colorado (1, 2) include several mining districts that have produced copper-bearing ores. (See fig. 24.) The rugged mountains, which cover about 11,000 square miles, are composed chiefly of nearly horizontal volcanic formations overlying a basement of pre-Cambrian intrusive and metamorphic rocks and Paleozoic to Tertiary sedimentary rocks. The principal mineral-producing counties include one of the richest gold- and silver-bearing areas of the State, the San Juan mining district (3). San Juan, Ouray, San Miguel, Hinsdale, and Dolores Counties in this district and Saguache County in the northeastern San Juan Mountains yielded about 41 percent of the total copper production of Colorado from 1858 to 1932 (3, 4). The production of copper in the San Juan region, excluding that of minor counties, is about 132,000,000 pounds, valued at $20,000,000. Although this is chiefly byproduct copper from the treatment of complex gold-silver-lead-zinc ores, the value of the copper production of a few mines exceeded that of the lead and zinc, although not that of the gold and silver.

San Juan County and southern Ouray County, at the heart of the mineralized area, have yielded more copper but less lead than surrounding counties, indicating a definite but small increase in copper nearer the centers of mineralization. The ratio of copper to lead in the San Juan County ores has been about 0.15, as compared to averages of 0.03 to 0.08 for adjacent counties and of 0.07 for Colorado as a whole. In 1931 and 1932 the copper production of San Juan County (2,636,505 pounds) exceeded that of lead (1,945,000 pounds), because the chief product was gold- and silver-bearing base-metal ore from the deeper levels of the Shenandoah-Dives mine, near Silverton. Saguache County likewise showed increased copper production in 1926 to 1930 from the copper-silver lead ore from the deeper levels of the Rawley mine.

Most of the copper in the San Juan region apparently resulted from higher-temperature facies of the base-metal mineralization; hence as deeper levels nearer the centers of mineralization are exploited, the proportion of copper may be found to increase. Typical examples of some of the copper-bearing ores are described below, but reference should be made to other sources for descriptions of the gold and silver ores and other complex ores containing only small proportions of copper.

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San Juan and Ouray Counties.—The north half of San Juan County and the southernmost tip of Ouray County embrace the structural center of late Tertiary igneous activity and mineralization in the western San Juan region. The uneroded volcanic formations are as much as 4,000 feet thick and include andesitic, latitic, and rhyolitic flows and tuffs. These rocks are fissured and faulted and have been invaded by many dikes and stocks ranging from dioritic to granitic in composition, with minor syenitic intrusions. The ores occur chiefly in simple fissures or less commonly in stocks and complex lodes and are probably of late Miocene or early Pliocene age. Most of the deposits are clustered about a sunken block of

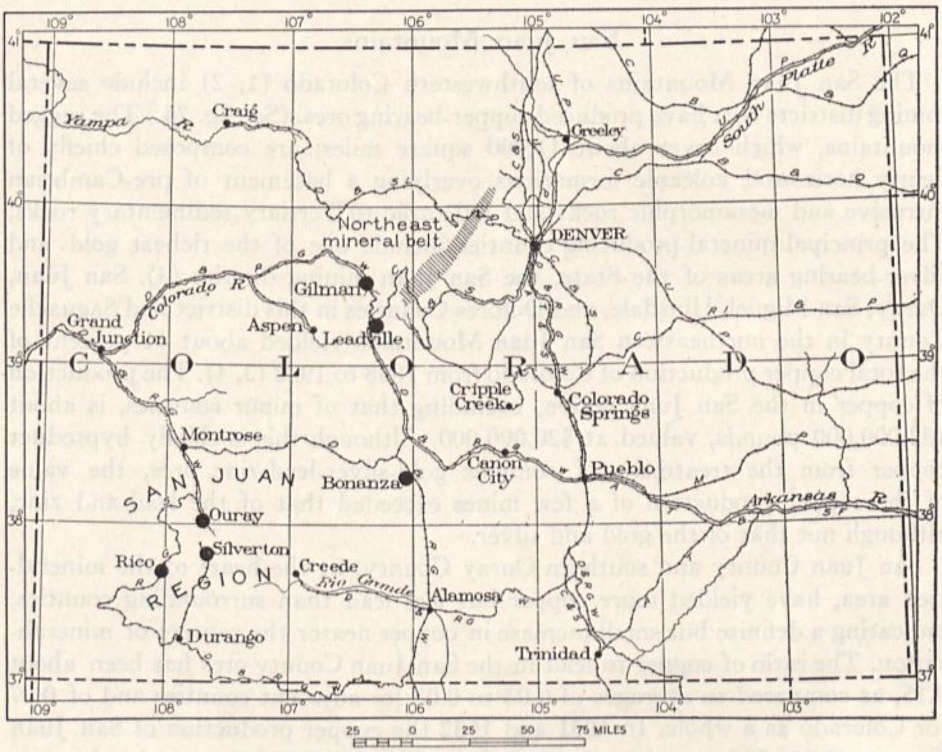

FIGURE 24.—Map of Colorado, showing copper-producing districts.

the volcanic rocks that included one of the later volcanic complexes. The sunken block is triangular, 8 to 10 miles in diameter, and centers within the Silverton quadrangle (5).

Most of the fissures and dikes along which veins occur are radial to the subsided block; some are parallel to or concentric with the marginal faults. The chief intrusives in the central area were localized by the subsidence along parts of the faulted margins; others occur 6 to 8 miles from the marginal faults. Some of the structural features are thus comparable to those of the Hebridean central volcanic complexes.

At the Silverton center an early doming of the crust by surgence of a central magma reservoir developed concentric and radial tension and shear fissures and dike intrusions, followed by subsidence, renewed fissuring, and intrusion of quartz monzonite in stocks and dikes, especially around and outside the marginal faults. The fissuring that localized the ore bodies was of late origin and associated with final adjustment of the subsiding central block. At least 250 and possibly more than 300 square miles of the western San Juan region came within the sphere of influence of this volcanic center. The preponderance of base-metal ores near marginal faults and of the silver-gold ores low in base metals in more distant fissure systems shows that ore zoning was controlled chiefly by the major features of structure. The veins intersect the exposed intrusive bodies and show but little zonal relation to them, indicating a deep-seated source of the mineralizing agencies.

Veins in a zone of northwestern fissures southeast of the sunken block in the Arrastre Basin and Cunningham Gulch regions range from gold-bearing base-metal facies with appreciable chalcopyrite to lead ores with silver-bearing tetrahedrite of lower copper and gold content. The Shenandoah-Dives and Highland Mary mines (6, 5) occupy extremities of a fissure system 2 miles or more long. Ores in the northern part of this system (3,000 to 6,000 feet southeast of the marginal faults of the sunken block) consist of pyrite, chalcopyrite, sphalerite, and galena. Native gold is generally associated with the chalcopyrite. Tennantite and tetrahedrite are rare or absent. The gangue is chiefly quartz with some chlorite and carbonates. Ore mined from 1928 to 1932 ranged from 0.15 to 0.32 ounce of gold and 2.6 to 5.0 ounces of silver to the ton, 0.35 to 0.7 percent of lead, and 0.5 to 1.4 percent of copper, with a little zinc. Ores in the southeastern part of the fissure system (extending about 3 miles south of the sunken block) consist of argentiferous tetrahedrite with pyrite, galena, chalcopyrite, and sphalerite in a gangue of quartz, barite, and some rhodochrosite or manganiferous calcite. The gold tenor is commonly lower than in the more northern shoots. Parallel veins on the southwest contain similar ores but probably averaged less copper than the deeper northern shoots of the Shenandoah-Dives. The principal mine workings of this region extend from about 1,000 or 1,500 feet to more than 3,500 feet above the main valley bottom.

Vein systems of northerly and northeasterly strike north of the sunken block in the Sunnyside Basin and Poughkeepsie Gulch regions have produced chiefly base-metal ores of high zinc content, with copper less than 0.5 percent. There are some veins and stock deposits of higher copper and gold content.

The Red Mountain district, along the northwestern margin of the sunken block, has produced much high-grade silver-copper-lead ore from chimneylike stocks in highly altered and silicified volcanic rocks. The ores were chiefly argentiferous galena near the surface but changed at depths of less than 300 feet to silver-rich copper ores, which passed downward into lower-grade pyritic ores. Some ores, such as those from the lower levels of the National Belle mine, consist chiefly of enargite and pyrite. Many copper minerals occur in these deposits, including bornite, chalcopyrite, enargite, stromeyerite, chalcocite, covellite, and tetrahedrite. The deepest deposits developed by shafts are from 1,000 to 1,300 feet below the surface.

Telluride and Ouray districts.—San Miguel County has produced metals to a value of about $116,000,000 (1929), about 86 percent of which is represented by silver and gold and less than 2.5 percent by copper. This county and the southern part of Ouray County embrace veins of northwesterly to westerly strike that extend radially outward from the northwestern part of the sunken volcanic center of the Silverton quadrangle. The silver-gold ores are closely associated with base-metal ores, and production from the deeper levels has shown an increasing proportion of base metals. The productive veins lie chiefly in andesitic tuff (San Juan tuff) but also in lavas of the overlying Silverton series and in the Paleozoic and Mesozoic sediments.

Most of these veins were precious-metal veins of moderate to low base-metal content (chiefly galena). In the Camp Bird and Tomboy mines, however, base-metal veins occur alongside of or near the gold ores but were only in part mined with them. In the base-metal ores the copper content is commonly lower than the lead and zinc content, but chalcopyrite is usually more abundant than in the precious-metal ores. Representative veins of this type are the Black Bear and Argentine veins, 2 to 3 miles northwest of the margin of the central sunken block. The principal ore minerals in the Black Bear vein are pyrite, sphalerite, galena, chalcopyrite, and native gold. Silver is associated with galena, although freibergite has been occasionally found. The gangue is mainly quartz with small amounts of rhodonite, rhodochrosite, and calcite. Past production and estimates of reserves indicate that the vein has a content of about 0.14 ounce of gold and 1.5 to 3.5 ounces of silver to the ton, 2 to 3 percent of lead, 1 percent of copper, and 3 to 6 percent of zinc. Many other base-metal veins near the northwestern and western margin of the Silverton center have been little developed, owing to their comparatively low gold and silver content and complex mineralogy, but they probably constitute a large reserve of copper-bearing ores.

Bonanza (*Kerber Creek*) *district.*—The Bonanza district (7, 8), in Saguache County, in the extreme northeastern part of the San Juan region, has produced metals worth nearly $7,700,000 (1929). The volcanic rocks belong to the lower part of the San Juan volcanic succession and have been domed and intensely faulted by the invasion of deep-seated and shallow magmas. The exposed intrusives consist of rhyolite and quartz latite porphyry. The larger ore shoots are chiefly confined to subordinate faults and fissures. Base-metal ores and low-sulphide manganiferous ores occur. Silver production from the manganiferous ores has been small. The base-metal ores contain lead-zinc and copper-silver shoots. The ore minerals are the common base-metal sulphides with the chief silver content in tennantite, but in a few veins, such as the Rawley, complex silver-bearing pyrite-copper ores underlay the galena ores to moderate depths. Chalcopyrite, bornite, enargite, chalcocite, covellite, and stromeyerite are present in the cupriferous ores, and a little bismuth is present in such minerals as cosalite.

Rico district.—Rico, in Dolores County, is chiefly a lead, silver, and zinc camp, but it has also produced some gold and copper; between 1858 and 1932 the copper amounted to 4,033 tons. The principal ore deposits occur in Pennsylvanian (Hermosa) sedimentary rocks that have been intruded by a stock of monzonite. The intrusive mass domed the adjacent rocks and produced considerable faulting, which was especially concentrated in a complex upthrust block at the east end of the elongated monzonite outcrop. Most of the ore has been taken from the rocks outside of the upthrust block but more or less surrounding it.

The ore occurs in fissure veins, in mineralized blanket breccias, and as replacement deposits in limestones, interbedded with sandstones and shales, adjacent to crosscutting fissures. In general, the ores are very complex, containing lead, zinc, silver, copper, and gold in addition to abundant pyrite. Some copper is therefore obtained as a byproduct in the treatment of all the ores; the greater part of it, however, has been obtained from two mines, from shoots in which the copper predominated locally over other metals except iron. These mines are the Black Hawk and the Mountain Springs-Wellington group, both situated along the prominent Black Hawk fault. The copper occurs as chalcopyrite, embedded in massive pyrite that replaces whole beds of limestone; fluorite is a common gangue, especially in the Black Hawk mine. Galena and sphalerite may or may not accompany the chalcopyrite. The copper grades out on the borders of the deposits into low-grade pyrite.

Aside from chalcopyrite, the only other copper mineral common at Rico is tetrahedrite. Associated with chalcopyrite and sulphides of the other metals, it is widely distributed in the different types of ore deposits but is valuable chiefly as a carrier of silver rather than as a source of copper.

Northeast half of the mineral belt

By T. S. Lovering

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In the northeastern part of the mineral belt that extends from Leadville to Boulder (see fig. 24) almost no ore has been mined directly for its copper content; by far the bulk of the copper produced has come from the lead-zinc limestone replacement ores of Leadville and Gilman. The pyritic gold ores of the Tertiary veins in the pre-Cambrian of the Front Range have produced an appreciable amount of associated copper in the aggregate, although individual deposits have seldom produced more than a few tons of copper a year. Locally copper ore from deposits formed by magmatic segregation in gabbroic rocks of pre-Cambrian age has contributed moderately to the output (9), but the production from such deposits has been sporadic and relatively unimportant.

Byproduct copper from Leadville commonly ranged between 500 and 2,000 tons of copper annually during the productive period of the camp. The total production is between 50,000 and 60,000 tons. At Gilman the copper produced annually seldom exceeded 100 tons prior to 1920 but since that year has commonly ranged between 1,000 and 2,000 tons, largely byproduct copper obtained during the mining of zinc ores. All the vein deposits northeast of Leadville have together produced much less than the Leadville district itself, but individual camps produce as much as 200 tons of copper a year. This production, as at Leadville, has come from many scattered deposits.

Leadville district.—According to C. W. Henderson (10) Leadville to the end of 1930 had yielded $446,167,000 worth of ore, of which 12 percent was gold, 43 percent silver, 21 percent lead, 21 percent zinc, and 3 percent copper. The rocks of the Leadville district, from the oldest to the youngest, comprise (*a*) pre-Cambrian granite, gneiss, and schist; (*b*) the Cambrian Sawatch quartzite, 135 feet thick; (*c*) the Ordovician Manitou or White limestone, about 95 feet thick; (*d*) the Devonian Chaffee formation, 107 feet thick; (*e*) the Mississippian Leadville limestone, about 120 feet thick; (*f*) the Pennsylvanian Weber (?) formation, about 1,250 feet thick; (*g*) late Cretaceous and early Eocene intrusive porphyries locally known as the White porphyry and the Gray porphyry; (*h*) an extensive and thick mantle of fluviatile, lacustrine, and glacial deposits.

The White porphyry, the earliest intrusive, is equivalent to muscovite granite in composition and is largely confined to an extensive sheet, but several small sills occur at other horizons. The later Gray porphyry includes several varieties of slightly different ages but of a composition between diorite and sodic quartz monzonite. Most of the Gray porphyry occurs as intrusive sheets, but dikes are not uncommon. The porphyry sheets localized many of the replacement ore bodies in the limestone. Postmineral rhyolite agglomerate pipes occur in the Leadville district and to the north.

Regional reverse faults trending north to northwest accompanied or immediately followed the intrusions. The reverse faults were followed by minor premineral normal faults and fissures trending from east to northeast, some of which slightly offset the earlier north-northwesterly faults. Ore deposition followed the minor normal faulting early in the Eocene epoch. In the mineral belt northeast of Leadville the reverse faulting was followed by the intrusion of stocks and batholiths of quartz monzonite. No comparable intrusive has been definitely recognized in the Leadville district. The distribution of ore bodies, principally those containing magnetite, suggests that older stocks may be present in Breese Hill. At the time of this stocklike intrusion or shortly after it the minor normal faults were formed. Later, probably during the Pliocene epoch, large-scale postmineral faulting divided the district into fault blocks. Most of the late faults trend north. Many new faults were formed during this period and in general trend north and dip west, but renewed movement along earlier faults was common.

Structural conditions governed the distribution and size of most of the ore deposits, but their form and their primary mineralogy are largely dependent on the country rock and on their relation to the Breese Hill stock. Silicate-oxide replacement deposits, unimportant commercially, were formed at relatively high temperatures in limestone close to the Breese Hill stock. Somewhat later and commonly at a greater distance are the mixed sulphide veins formed at moderate temperatures, mainly in siliceous rocks. Mixed sulphide replacement bodies from which much of the silver-lead production of the district has come were formed at moderate temperatures, chiefly in limestone at somewhat greater distances, and are best developed in the region lying just outside the zone of mixed sulphide veins.

Most of the copper has come from veins in or near the Breese Hill stock. Where the mixed sulphide veins cut siliceous rocks they may consist almost wholly of pyrite with interstitial chalcopyrite in a quartz gangue, but in a limestone the veins may expand into a replacement deposit consisting chiefly of sphalerite and galena, encased by a dense quartz envelope. At the expansion the chalcopyrite-pyrite ores may persist for a short distance laterally, but they soon grade into the lead-zinc ores. Commonly the pyritic ores are more valuable for their gold than for their copper. The copper content in the primary ores nowhere exceeds 3½ percent. Nearly all the pyritic ores contain some chalcopyrite (12, pp. 77–91). Some copper occurs in the replacement deposits, but it is relatively unimportant.

Much copper has come from supergene chalcocite. Chalcopyrite is probably as abundant as chalcocite, and nearly all the copper produced has come from these two minerals. The chalcopyrite is probably for the most part primary (11, p. 201).

Gilman district.—The rocks of the Gilman district (13, 14) are very similar to those of Leadville. The little-disturbed Paleozoic rocks have a monoclinal northeast dip. The Ordovician and Mississippian rocks, the commercially important ore beds, are restricted to the northeast wall of the Eagle River Canyon. The ore deposits have been found only in the pre-Pennsylvanian rocks. The Paleozoic sediments are broken by steep northeastward-trending faults and also by bedding thrust faults, all probably of small displacement. The brecciation along many of the faults (both steep and thrust) is out of proportion to the small displacement now shown, and the walls probably moved back and forth before finally coming to rest. These fault systems are both premineral, but a few northwestward-trending postmineral faults occur.

The primary ores are of the same age as those at Leadville but differ in form. Two general types are recognized—fissure veins in pre-Cambrian rocks and Sawatch quartzite and replacement deposits in the Leadville limestone and to a minor extent in the underlying formations.

Most of the ore in both veins and blankets was zinc-lead ore with very little copper. Most of the copper ores have been found in funnel-like downward projections of blanket replacement ore bodies. Some of this ore is very high grade chalcopyrite and contains little sphalerite and only moderate amounts of pyrite. However, in most of the funnel-like chimneys of ore extending below the replacement bodies the ore is chiefly pyrite with less chalcopyrite and tetrahedrite. Supergene copper minerals have contributed little to the production of the district. The total production of the district in terms of the recovered metals to the end of 1930 has been 3,250,000 ounces of gold, 10,500,000 ounces of silver, 17,000,000 pounds of copper, 110,360,000 pounds of lead, and 247,000,000 pounds of zinc.

Front Range mineral belt.—The northeasterly belt of Eocene porphyry stocks and dikes that extends from Breckenridge to Boulder lies almost wholly within pre-Cambrian schists, gneisses, and granite and coincides very closely with the belt of mineralization. There are many local centers of mineralization in the Front Range mineral belt. The small copper production has all been derived as a byproduct in mining other metals. Thus in the Montezuma, Georgetown, and Silver Plume districts the copper is a byproduct in the beneficiation of lead-silver ores, and in the Idaho Springs, Central City, and Ward districts the copper has been a byproduct in the mining of pyritic ores valuable chiefly for their gold. Supergene sulphide copper has been noted locally but is not of commercial importance.

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Copper in Idaho[1]

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Summary

Copper is widespread in Idaho, but relatively few deposits are of commercial interest. The Empire mine, in Custer County, with a production of over $14,000,000, and the Snowstorm mine, in the "copper belt" of the Coeur d'Alene region, Shoshone County, which has produced about $10,500,000, are by far the most productive copper mines in the State. Near each are less productive mines. Elsewhere the principal copper mines are the Harmony and Pope-Shenon, in Lemhi County. Several lead-silver mines, such as the Ramshorn, in Custer County, have yielded considerable copper, and so has the Copper Queen gold mine, in Lemhi County. Several properties, such as the Copper Camp and Werdenhoff, in Valley County, and some in the Seven Devils region, are relatively undeveloped but contain considerable copper ore.

Figure 25 shows the location of the principal districts containing copper ore. Many other districts have lodes containing copper minerals, and some have produced or will produce this metal under favorable circumstances.

The Empire and similar lodes in the Alder Creek district are contact-metamorphic deposits of Tertiary age. Probably nearly all the others are Mesozoic (1). The Snowstorm is a disseminated deposit in quartzite. The Pope-Shenon and similar deposits occur along shear zones in schist and quartzite. Both the Snowstorm and the Pope-Shenon may be related to regional igneous metamorphism. The Ramshorn and others typify the tetrahedrite-rich variety of the many sideritic (chiefly lead-silver) lodes in shear zones. The other copper-bearing lodes are mostly related to the auriferous quartz veins in and near granitic rocks, or else are contact metamorphic. The three principal copper districts are described in greater detail below.

Alder Creek district

The Alder Creek district (2, 3, 4), near Mackay, Custer County, was discovered about 1884. Of the several deposits the Empire is the only one with much production. Figure 26 shows the general geology of the district. The Empire, White Knob, and Horseshoe mines are along the contact between Brazer limestone (upper Mississippian) and a Miocene granitic intrusive with related porphyries. Smaller prospects in quartzite and limestone (Ordovician?) lie west of the intrusive. The commercial ore bodies are limited to the intrusive rock and a relatively narrow silicated zone in the adjoining limestone. The gangue and the country rock contain contact-metamorphic silicates, and locally a little marble is present.

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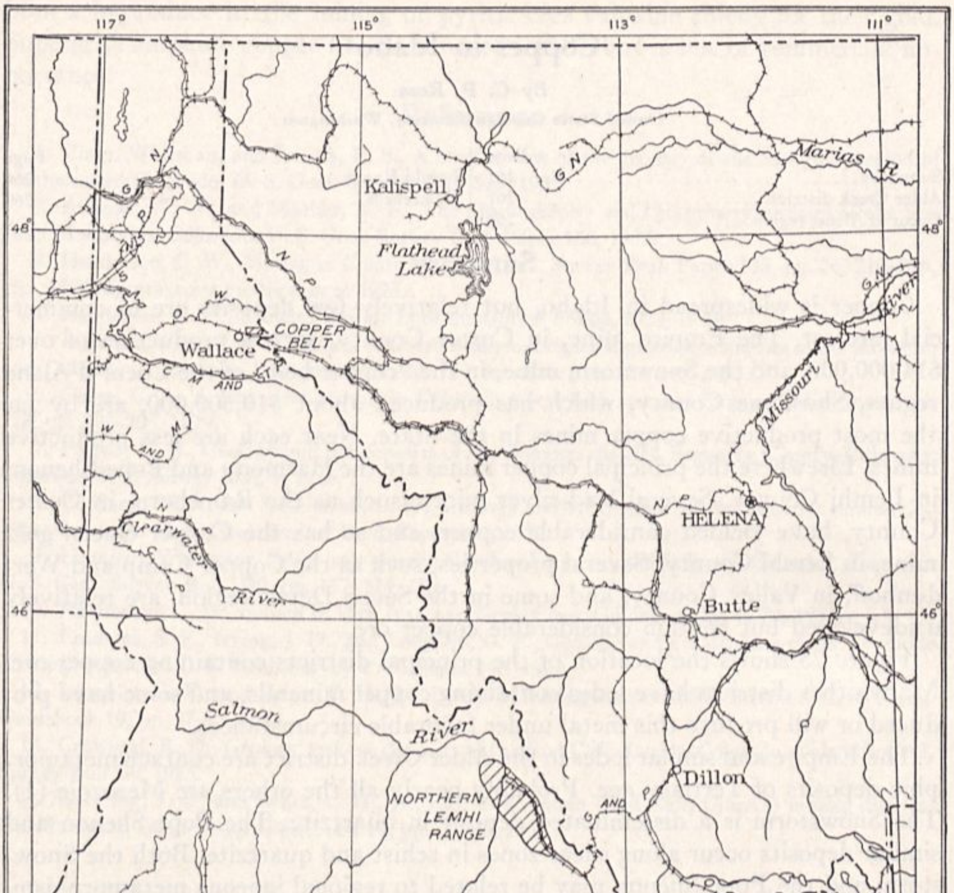

FIGURE 25.—Principal copper-mining districts in Idaho.

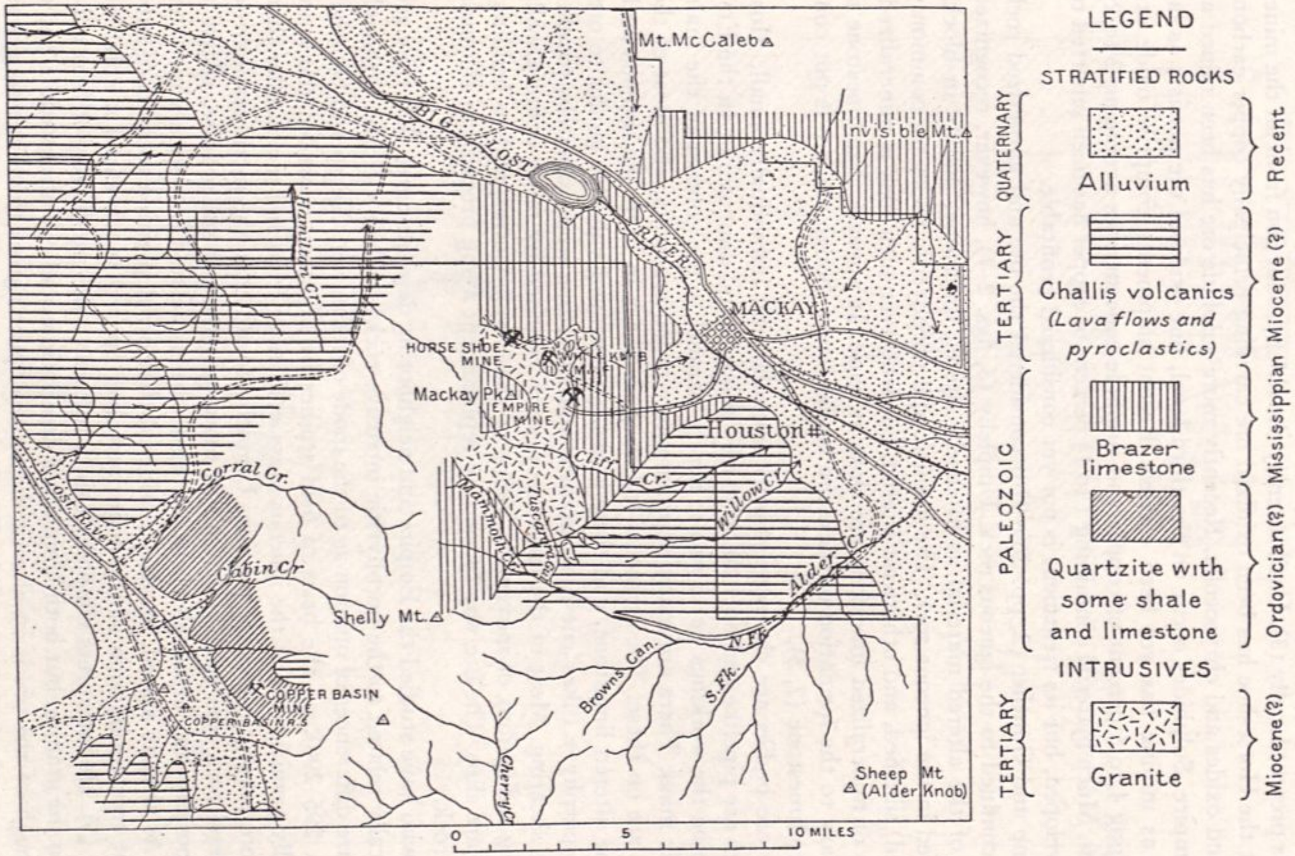

FIGURE 26.—Geologic sketch map of the Alder Creek mining district, Custer County, Idaho. (After C. P. Ross, Idaho Bur. Mines and Geology Pamphlet 33, 1930.)

Almost all the ore so far developed is copper ore containing some gold and silver. The principal hypogene copper mineral is chalcopyrite. A little tetrahedrite is present locally (3). Until recently the chief production from all the mines except the Horseshoe has been oxidized ore carrying principally copper carbonates and oxides and chrysocolla. Recently more sulphide ore has been mined at the Empire. Sulphides occur on the third level, but oxidized ore persists as far down as mining has yet been carried. Recent shipments comprise oxide ore averaging 4 to 5 percent of copper and sulphide concentrates averaging 2 to 2½ percent. Much material containing 1 to 1½ percent of copper has been reported to be developed, but its treatment is not yet considered profitable.

Kemp and Gunther (2, pp. 269–270) considered the ore and garnetized rock to be confined to the igneous rock. Umpleby (3, figs. 2–7), however, recognized much of the altered material as intensely altered limestone, mainly in blocks engulfed in the igneous rock. The granitic and porphyritic rocks are commonly sheared, silicified, and otherwise altered, but wherever such rock is mineralized, blocks of mineralized limestone are close at hand. It appears that limestone is necessary to the formation of these ore bodies, even though the ore is not confined to limestone (2, 3).

The ore bodies are characteristically irregular and individually small. Most of them are pipelike and only 20 or 30 feet in horizontal dimensions. In the Empire mine the workings lie in an arc nearly parallel to the contact of the main granitic mass. There are many approximately radial crosscuts, and most of the stopes are on these. The crosscuts follow shear zones in both the igneous rock and the altered limestone, and these zones have proved valuable guides to ore. Many porphyry dikes cut both granite and limestone approximately parallel to this shearing. Most of the larger stopes are bounded by fairly definite walls showing indications of movement. Some of these walls correspond to bedding; others are slips. The ore was formed by replacement along preexisting channels in the rock.

All who have studied the Empire and neighboring deposits agree that they are genetically related to the porphyritic intrusive rocks in their vicinity, although there are differences of opinion as to the mode of formation. Kemp and Gunther (2, pp. 295–296), on the basis of field studies by Gunther, regarded the more typically granitic core of the igneous mass as distinct from and much older than the more porphyritic outer portion. Umpleby found that the more porphyritic peripheral rock was merely the chilled marginal phase of the granite, which is itself porphyritic, although there are also various related but somewhat later dikes. As already stated, he also considered that ore deposition took place subsequent to consolidation of the main intrusive. Spurr has advanced a different theory (5). He interprets Umpleby's data to mean that ore deposition was confined to the granite, but both Umpleby's descriptions and my observations show that much of the ore is in altered limestone. Spurr agrees that limestone was necessary to the formation of the Empire deposits but differs as to the interpretation of the contact metamorphism.

On the basis of an examination in 1929 (4), I agree in essentials with Umpleby, with the modification that the granite and related porphyries are Tertiary and

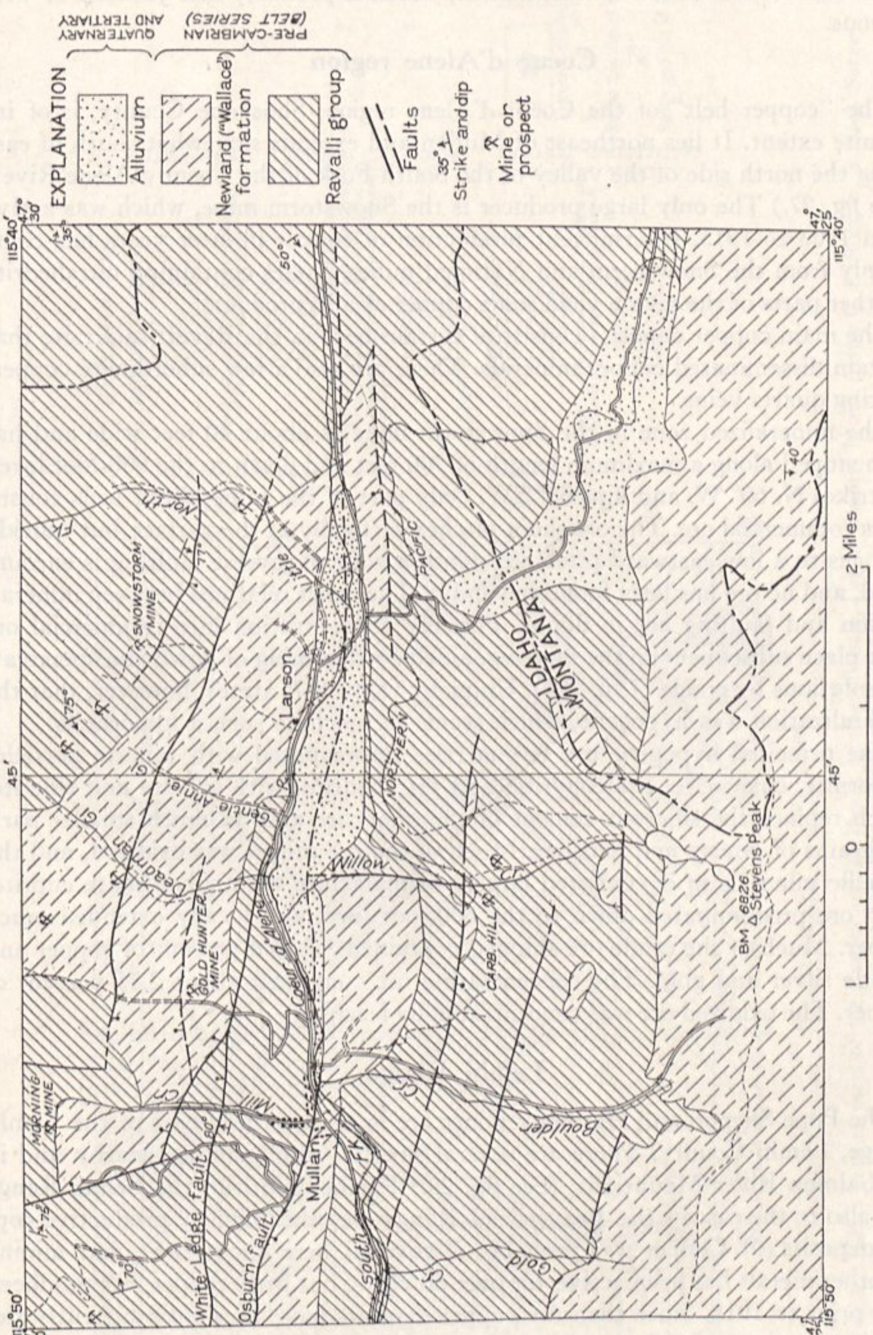

FIGURE 27.—Geologic map of the region around Mullan, Idaho. (After Calkins and Jones, U. S. Geol. Survey Bull. 540, pl. 3, 1914.)

quite distinct from the Idaho batholith, which is probably late Jurassic or Cretaceous.

Coeur d'Alene region

The "copper belt" of the Coeur d'Alene region, Shoshone County, is of indefinite extent. It lies northeast of Mullan and extends somewhat south of east along the north side of the valley of the South Fork of the Coeur d'Alene River. (See fig. 27.) The only large producer is the Snowstorm mine, which was active from 1903 to 1915. Intermittent production of copper in later years has come mainly from the Snowstorm and National mines. Lodes containing tetrahedrite in other parts of the region yield some copper as a byproduct.

The main copper deposits consist of certain beds in the Revett quartzite that contain disseminated copper minerals. There are also a few subordinate copper-bearing quartz veins.

The mineralized zone in the Snowstorm mine is about 40 feet wide and has been stoped along a maximum length of 700 feet and down to the 900-foot level. It strikes N. 60° W. and dips 65° SW. Only part of the mineralized beds constitutes commercial ore. The ore shoot pitches vertically at the surface but quickly changes to a low eastward pitch. At depth a zone of reverse faulting is encountered, and no ore has been found beyond it. The exact relations between mineralization and faulting are in doubt. Possibly concentration into commercial ore took place subsequent to the faulting, aided by damming of downward-percolating solutions by gouge (7, p. 207). Umpleby (8, p. 117) states, however, that the mineralization was hypogene, which seems to preclude such a hypothesis.

The principal hypogene ore is quartzite impregnated with minute particles of bornite, chalcocite, chalcopyrite, and tetrahedrite, with sericite and siderite, which replace the siliceous cement of the quartzite and, in much smaller part, the grains of quartz and feldspar. Much of the ore mined was oxidized, and the metallic minerals in it consisted largely of malachite with subordinate cuprite. Such ore predominated down to the 600-foot level and locally extended much deeper. Much of the crude ore shipped contained 3.5 to 4 percent of copper and a little silver and gold. The concentrating ore contained about 2.75 percent of copper. The oxidized ore was concentrated by leaching.

Lemhi Range

The Pope-Shenon and Harmony mines are in the northern part of the Lemhi Range, Lemhi County. There are several smaller, similar mines nearby and in the Salmon River Mountains. (See fig. 28.) Farther south in the Lemhi Range and also to the east in the Beaverhead Range are other slightly productive copper deposits (9). Copper was probably discovered here about 1854, and mining for other metals has been active for over 50 years, but little copper was produced here prior to 1918. Since then the copper deposits have been intermittently developed.

The Pope-Shenon, Harmony, and associated lodes are all chiefly replacement deposits with some fissure filling on shear zones in impure quartzitic rocks of the Belt series. Most of the shear zones trend northwest, independently of both bed-

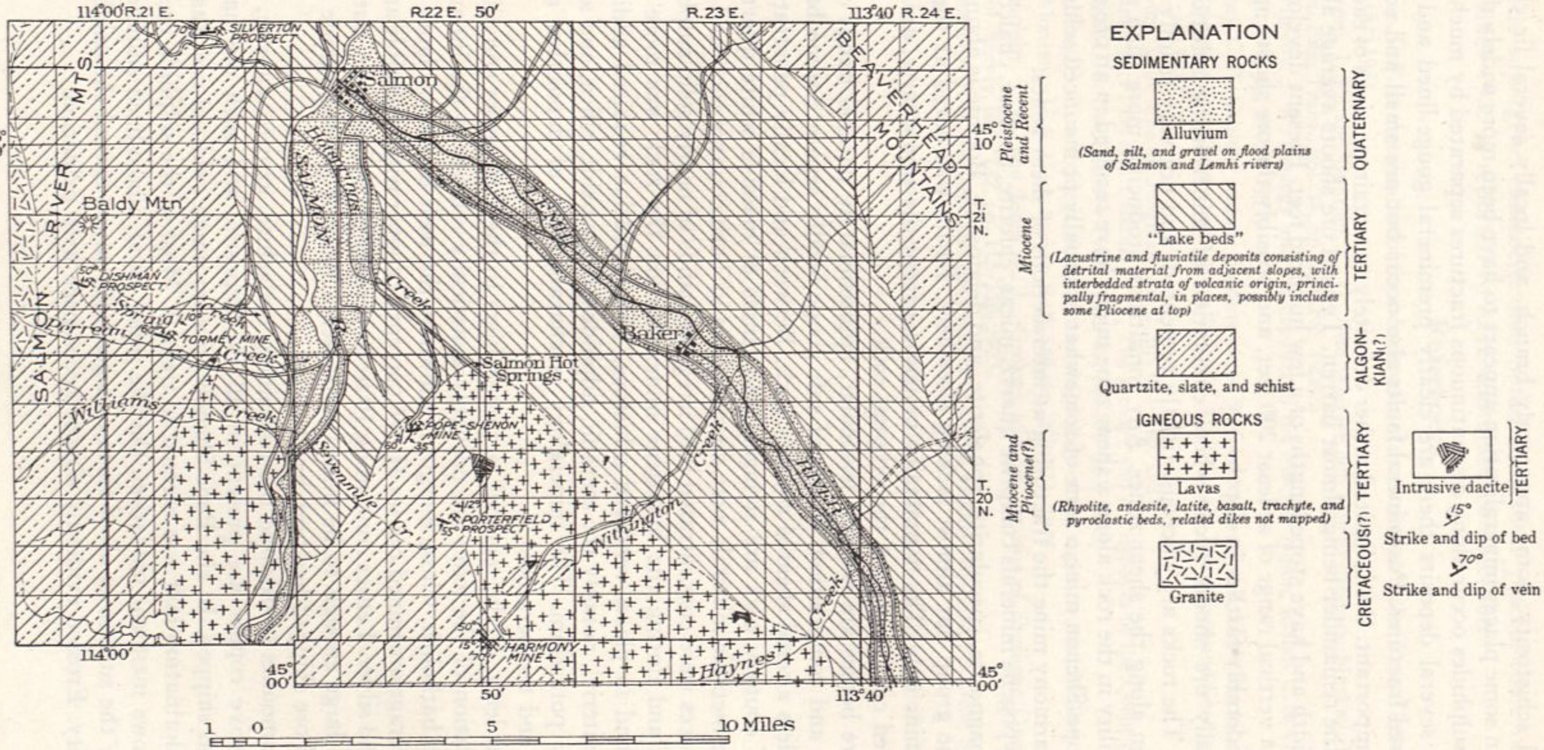

FIGURE 28.—Geologic sketch map of parts of the Eureka and McDevitt mining districts, Lemhi County, Idaho. (After C. P. Ross, U. S. Geol. Survey Bull. 774, pl. 1, 1925.)

ding and schistosity; some apparently branch, and locally several lie close together. In some places mineralization appears to have been more widely diffused, and the sulphides occur along discontinuous fractures separated by much barren rock. In several deposits there are clearly premineral gouge-lined and locally mineralized fractures. Postmineral faults also occur but are small and economically unimportant. Ore is limited rather definitely to certain portions of each lode, most of the remainder being almost barren. Typical ore shoots average about 10 feet in width and have stope lengths of a few hundred feet. Present developments indicate a vertical range of at least 200 feet, and possibly the ore shoots may persist considerably farther in depth.

Generally ore shoots occur where circulation of mineralizing solutions was readiest. The rocks are siliceous, tightly cemented, and not very readily permeable, even along the shear zones. Any conditions producing more than average permeability in the rock along a shear zone might have resulted in an ore shoot—at the Pope-Shenon mine a zone of somewhat unusually pronounced schistosity; at the Harmony mine the fracturing at intersections of shear zones.

The hypogene minerals comprise quartz, micas, chlorite, epidote, chalcopyrite, pyrite, magnetite, specularite, sphalerite, and delafossite. Bornite is abundant in the Nellie group but almost lacking elsewhere. Barite was noted at the Pope-Shenon mine only. The nonmetallic minerals, except the vein quartz, are largely the altered components of the original rock.

The ore bodies are roughly lenticular, approximately parallel bands of variable size and composition. Bands of soft gouge locally separate some bands of more or less altered sheared country rock. Between and locally penetrating the bands of country rock are stringers and lenses of massive white quartz. The hypogene metallic minerals were disseminated in both country rock and quartz and in places were concentrated into irregular bands of nearly solid sulphide.

Before and during the hypogene mineralization the rock was more or less crushed and in places rendered schistose. The alteration required addition of foreign material, notably the metallic sulphides, ferric oxide, silica, and alkalies, especially potassium. The mineralogy is characteristic of deposition at high pressure and temperature.

Part, at least, of the regional metamorphism in the Belt rocks and all of the mineralization of the lodes are probably genetically related to the intrusion of the Idaho batholith, whose margin is shown at the west border of figure 28.

The average ore mined carries 2½ to 6 percent of copper with negligible amounts of gold and silver. Lenses containing 10 to 20 percent of copper occur, but few of these are large enough to be mined separately. Most of the high-grade unconcentrated ore shipped has been hand-sorted.

Small amounts of oxidized ore containing malachite, azurite, cuprite, and in places native copper are present in all the deposits, and such ore has been mined and shipped. In the Pope-Shenon mine so much oxidized ore was found that a chlorination mill was erected to treat it. Most of the sulphide ore in the mines shows incipient oxidation. On the other hand, unoxidized sulphides are very near the surface in all of them and generally much exceed the oxidized ore in quantity. Erosion evidently almost keeps pace with oxidation.

A little supergene chalcocite was noted in several places; some of the ore mined since 1923 is reported to have contained considerable.

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A little supergene chalcocite was noted in several places; some of the ore mined since 1923 is reported to have contained considerable.

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The Michigan copper district

By T. M. Broderick and C. D. Hohl

Calumet & Hecla Mining Co., Calumet, Michigan

Geography

The mines in the copper district of Michigan lie within a belt from 2 to 4 miles wide and more than 100 miles long (fig. 29). The central part of this belt, about 26 miles in length, has furnished over 95 percent of the total production of the district. By far the greater part of the total has come from mines in Houghton County. Keweenaw County, to the north, ranks second. The production from Ontonagon County, to the south, has been very small.

The most prominent topographic feature of the district is a narrow flat-topped plateau rising to a general level of 500 to 600 feet above Lake Superior and cut by several low transverse valleys. This plateau trends northeastward and projects into Lake Superior as Keweenaw Point.

The chief industry of Houghton and Keweenaw Counties is mining. The smelting is all done in Houghton County. Lumbering was formerly of importance but has declined, as the original timber has been removed, while agriculture and dairying are gradually expanding.

The district has the advantage of Great Lakes transportation and is also connected with outside points by railroads and by good highways. By far the greater part of the power used in the district is generated by coal shipped in by boat. A small fraction of the electric power is generated by hydroelectric plants on the Ontonagon and Sturgeon Rivers.

Geomorphology

The area underlain by the Keweenawan traps forms a long, narrow plateau with small monadnocks rising above the general level. Especially toward the northern and southern parts of the district long monoclinal ridges with longitudinal valleys between them were formed by the erosion of the alternate inclined beds of varying hardness. The sandstone and conglomerate areas, which lie on both sides of the basalt plateau, have been eroded to form the present lowlands near the lake shores.

These major preglacial features were not materially changed during glaciation. The old weathered rock surfaces were scoured off, and the topography was smoothed and rounded somewhat. The minor topographic details are determined by the irregularities of a deposit of drift 200 feet or more in maximum thickness, which was laid down by the ice and glacial streams. This drift seriously hampers the exploration and development of the copper deposits. In addition to the drift deposits are those formed by the lakes along the south margin

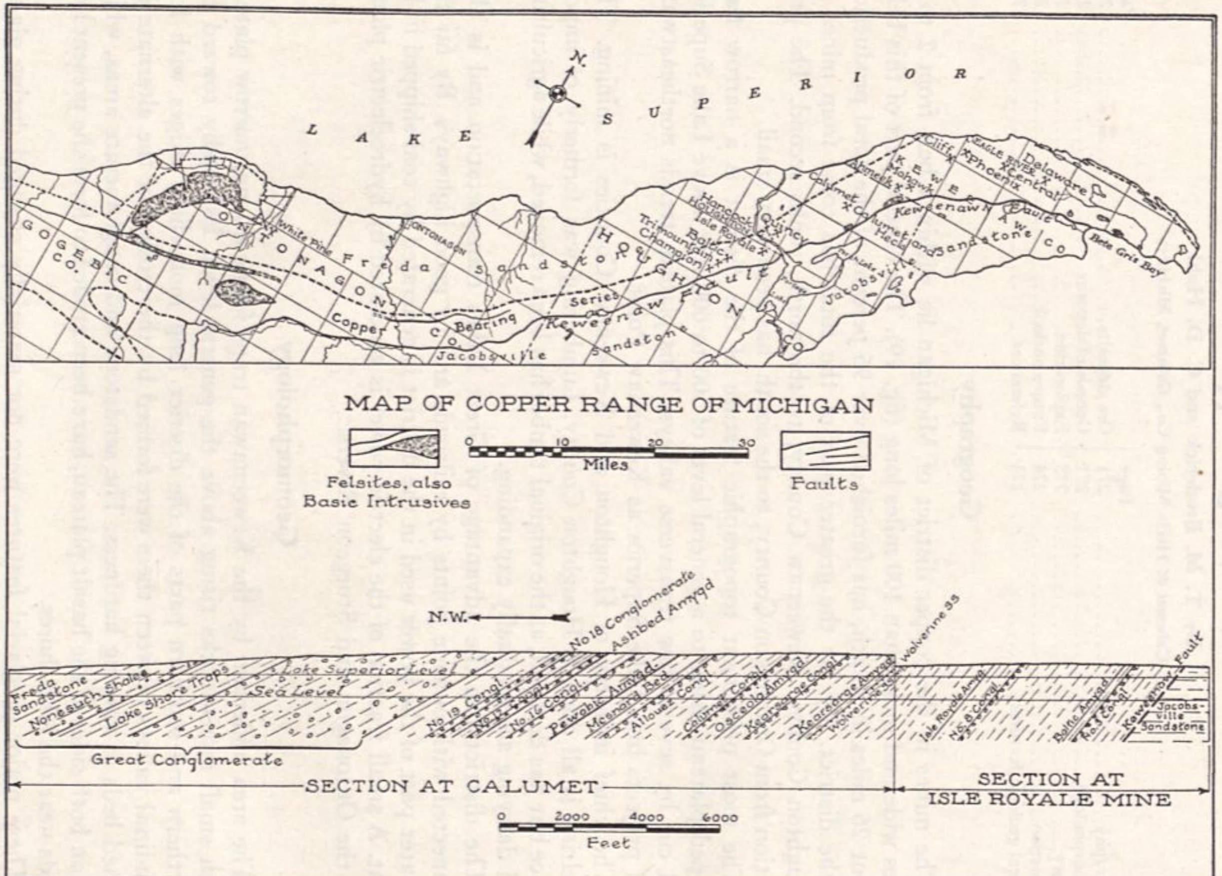

FIGURE 29.—Map and cross sections of Copper Range of Michigan. (After Broderick and Hohl, Min. Cong. Jour., 1931.)

of the ice. Several old beach lines were formed by the glacial predecessors of Lake Superior, and the highest one in the copper country is about 700 feet above the present lake level.

History

Copper mining in Michigan was started by a prehistoric race whose ancient pits and trenches were found by the white explorers. They uncovered many of the subsequently most productive deposits. At the time of the first white explorers no mining was being carried on, and the Indians then living are said to have had no knowledge of the ancient workers. Among the earliest references to the native copper are the records of Jesuit priests who visited the district in the middle of the 17th century. A glacial boulder of native copper weighing nearly 2 tons was noticed by the early explorers on the bank of the Ontonagon River. It was finally taken to Washington in 1843. In 1841 a report by Douglass Houghton, first State geologist of Michigan, aroused interest in the economic possibilities of the copper deposits, and exploration and development by individuals and companies began. The first paying deposit was the Cliff fissure vein, discovered in 1845. Two other fissure veins were opened successfully, the Minesota in 1849 and the Central in 1856.

The first amygdaloid deposits to be worked were on the Isle Royale (1852) and Pewabic (1856) lodes. The Calumet conglomerate deposit was discovered in 1864, followed by the Osceola and Kearsarge lode discoveries 10 years later. The most recent discovery was the Baltic lode, in 1882.

Refined copper produced in Michigan district in 1929, in pounds

Company	Calumet conglomerate	Kearsarge amygdaloid	Baltic amygdaloid	Osceola amygdaloid
Calumet & Hecla Consolidated:				
Mine	35,377,000	35,744,025		18,237,000
Tailings reclamation	33,511,000			
Copper Range:				
Champion			20,660,701	
Baltic			2,127,926	
Trimountain			1,408,689	
Mohawk		20,043,127		
Isle Royale				
Quincy				
Seneca		2,999,882		
	68,888,000	58,787,034	24,197,316	18,237,000

Company	Isle Royale amygdaloid	Pewabic amygdaloid	Ahmeek fissure	Total
Calumet & Hecla Consolidated:				
Mine			960,975	123,830,000
Tailings reclamation				
Copper Range:				
Champion				
Baltic				24,197,316
Trimountain				
Mohawk				20,043,127
Isle Royale	10,864,085			10,864,085
Quincy		4,459,426		4,459,426
Seneca				2,999,882
	10,864,085	4,459,426	960,975	186,393,836

Production

The Michigan copper district is the second largest producer of copper in the world, having produced 8,403,640,000 pounds of copper and paid $328,603,053 in dividends from the beginning of mining in 1845 to the end of 1930. Of the total copper, about 44 percent came from one ore body, the Calumet conglomerate, and 49 percent was obtained from five amygdaloid ore bodies, the Kearsarge, Baltic, Pewabic, Osceola, and Isle Royale. The fissure deposits, so important in the early history of the district and so interesting geologically, have contributed less than 2½ percent of either the total copper produced or the dividends paid. The district produced a total of 186,393,836 pounds of refined copper in 1929, distributed among the various lodes and companies as shown in the table on the preceding page.

The next table summarizes the total production of the principal lodes from the beginning of operations to the end of 1930. Over 100 mining companies have contributed to this total production, but only 13 have produced over 100,000,000 pounds each.

Total production from principal lodes in Michigan copper district to the end of 1930

Lode	Refined copper	
	Pounds	Percent of total
Calumet conglomerate	3,682,803,900	43.8
Kearsarge amygdaloid	1,462,502,489	17.4
Baltic amygdaloid	991,959,108	11.8
Pewabic amygdaloid	913,362,355	10.9
Osceola amygdaloid	494,328,432	5.9
Isle Royale amygdaloid	265,292,192	3.2
Atlantic amygdaloid	142,840,804	1.7
Allouez conglomerate	69,521,253	.8
Nonesuch sandstone	18,623,044	.2
Evergreen series	125,960,452	1.5
All fissures	203,440,975	2.4
All others	33,004,672	.3
	8,403,639,676	

General geologic features

In Keweenawan time some hundreds of basaltic flows were extravasated in and around the Lake Superior Basin, forming a series thousands of feet in thickness. Felsite conglomerates are abundant and thick in both the lower and upper parts of the Keweenawan but are subordinate to the flows in number and thickness in the middle of the series. Felsite and quartz porphyry flows are sparingly interbedded with the traps, and the whole series is intruded by gabbro and associated acidic differentiates. The intrusives range in size from small masses, such as that of Mount Bohemia in Michigan, to the great Duluth gabbro of Minnesota. These intrusives are especially abundant toward the base of the series on both limbs of the Lake Superior syncline. The largest, the Duluth gabbro, lying along the plane of unconformity at the base of the Keweenawan, is about 10 miles thick and forms a tabular body dipping with the overlying lavas toward the center of the syncline. Thus the series has a large intrusive mass at its base, of which the smaller intrusives in the Michigan copper district are probably offshoots. The sediments, chiefly felsitic debris, are all considered land deposits, derived from felsitic bodies that lay down the present dip, toward the center of Lake Superior. The flows are believed to have come from vents in the same neighborhood, and the intrusives to have been derived from the same magmatic chamber as the flows.

The area covered by the Keweenawan flows and sediments is enormous, extending from Michigan into Wisconsin and southward to Taylors Falls, Minnesota. Thence it extends up the north shore of Lake Superior, forms Isle Royale, and occurs on the shores of Black Bay and Nipigon Bay in Ontario. Keweenawan rocks are also found at the east end of the lake on Michipicoten Island and Point Mamainse, indicating their continuity throughout the Lake Superior Basin. This is one of the large areas of the plateau type of basalts in the world. In general structure it is a synclinal basin, the rocks dipping mostly toward the lake. The fact that it is possible to correlate the main horizons of the series from Keweenaw Point, on the south limb of the syncline, across the lake to Isle Royale, on the north limb, suggests that the source of material lies somewhere between. Detailed studies of the lavas and sediments in Michigan and Wisconsin accord with this view, in suggesting a source down the present dip.

There are nearly 400 flows in the Michigan sections, with intercalated sediments at 20 to 30 horizons. The lavas are mainly basaltic, with or without olivine. More rarely acidic flows such as felsites and quartz porphyries occur. A few flows of intermediate composition are known. Considering their age the rocks are surprisingly fresh, and most of the alteration they have suffered seems to have been deuteric or hydrothermal, rather than due to ordinary weathering. Recent studies indicate a cyclic relation between the different flow types and the sediments.

On cooling each lava flow gave off great quantities of gas, which collected into bubbles and rose to the top of the flow, where most of it escaped. But as the flow became cooler, it also became more viscous, and finally the gas bubbles were entrapped near the top, forming a cellular capping. In some flows the entrapped bubbles flattened out horizontally and coalesced with other flattened vesicles. In many flows the vesicular crust was broken up into fragments by subsequent movement or by further explosive outbursts of gas from the still liquid interior of the flow. These fragments of vesicular rock tended to pile up in irregular heaps on the tops of the flows. Later filling of the vesicles produced the amygaloids, which are classified as cellular, coalescing, or fragmental, according to their physical condition and method of formation as just described. These amygdaloidal tops are distinctly red, and examinations of the polished sections, supported by chemical analyses, reveal a steady increase in hematite toward the tops of the flows. This hematite was formed by oxidation of the original iron-bearing minerals of the traps, evidently at high temperatures and probably while the flows were solidifying. The oxidation was accomplished largely by the escaping gases, although atmospheric oxygen may have played a part.

Most of the flows followed one another so closely that there is no evidence of any erosion or normal weathering between them. Occasionally, however, there was an interval long enough to allow the surface to become broken up and to permit the finer sand thus produced to sift in between the larger fragments, forming what is known as scoriaceous amygdaloid. If the interval was long enough and other conditions were favorable, felsitic debris was carried in and deposited on the weathered surface, forming a felsite conglomerate. Thus we have scoriaceous amygdaloids commonly underlying or preceding conglomerates, although not all scoriaceous amygdaloids are overlain or followed by conglomerates.

The structure of the district is rather simple. (See fig. 29.) The large ore bodies so far found are all on the Keweenaw Peninsula, on the south limb of the Lake Superior syncline. The beds dip to the northwest at increasingly flatter angles toward the synclinal axis. They are cut off on the southeast by the Keweenaw fault, a thrust fault dipping nearly parallel with the beds and bringing the Keweenawan lavas and conglomerates on the northwest side against the Cambrian sandstone on the southeast side.[1] There are many branches of this fault in the lower part of the series, and where the beds have transverse folds there are associated transverse fissures. Although there was probably considerable movement on the Keweenaw fault in late Keweenawan and Paleozoic time, the main structural features, such as the great syncline, the minor transverse folds, and numerous faults and fissures, including the Keweenaw fault, were well developed when copper deposition occurred.

Ore deposits

More than 90 percent of the copper production of the district has come from six ore bodies—one in the Calumet conglomerate and the other five in the Baltic, Isle Royale, Kearsarge, Osceola, and Pewabic amygdaloids. (See fig. 29.) All these deposits are in the central portion of the series, which consists chiefly of lava flows. The ore mineral is native copper. Although native silver occurs in minor amounts, it is not usually separated from the copper in treatment. Copper sulphides and arsenides also occur in some of the ore bodies and fissure veins but not in commercial amounts.

The Calumet conglomerate ore body occurs in a felsite conglomerate. Although known for many miles as a sedimentary deposit, over most of its known extent it is a thin sandstone or shale, in many places but a few inches in thickness. At Calumet, however, it opens out into a body from 5 to more than 20 feet thick and becomes much coarser, with many pebbles and boulders 6 or 8 inches in diameter and some much larger. This conglomerate lens lengthens and thickens down the dip, and the copper is confined to this body, the depositing solutions apparently having been unable to penetrate the sandy or shaly margins that close in on the conglomerate lens like the sides of an inverted funnel. The copper, with adularia, epidote, calcite, and quartz, was deposited chiefly by replacement of the finer material between the pebbles. The richest mineraliza-

[1] The usage of the United States Geological Survey is followed in classifying these formations as Keweenawan and Cambrian.

tion occurred rather near the surface, where the solutions flowed through the thinner portions of the lens. Zeolites or zeolitic minerals, such as datolite and prehnite, are not found in the Calumet conglomerate. The rock immediately associated with the copper is bleached as a result of the removal of the primary hematite in the felsite pebbles and of the detrital hematite grains in the finer cementing material by the ore-depositing solutions.

In the upper levels mineralization was continuous over large areas, so that continuous stoping was possible, and in most places the entire thickness of the pebbly portion of the conglomerate was mined. In the deeper levels the mineralization was more erratic, and despite efforts to extract only the richer parts of the conglomerate, both by restricting the areas mined and by cutting down the width of the stopes, the copper content of the rock sent to the mill steadily declined. In the upper parts of the mine there were large areas that yielded 4 percent or more of copper. In the bottom levels highly selective mining would be necessary to obtain 2 percent.

The mineralized amygdaloid lodes are generally permeable because of their fragmental character, although the Pewabic amygdaloids are permeable in part because of the coalescing of the vesicles. None of the numerous cellular amygdaloids have been found to contain copper in commercial amounts. A greater variety of minerals are found in the amygdaloid lodes than in the conglomerate lode—among them quartz, epidote, chlorite, calcite, pumpellyite, adularia, sericite, ankerite, datolite, prehnite, and some zeolites. In most of these deposits the rock alteration immediately associated with the deposition of the copper has resulted either in the total removal of the iron originally in the primary hematite of the lode or in its reduction to the ferrous state and incorporation in ferrous silicates. In the amygdaloid deposits there are large unmineralized areas, chiefly to be explained by the fact that they are less permeable than the surrounding mineralized amygdaloid. They may be very thin or nonfragmental and trappy. Stoping widths in the amygdaloids are variable, ranging commonly from 6 to 18 feet and locally to much greater widths. Perhaps an average of all past stoping would be 13 feet. The average copper recovery of the amygdaloid lodes has been very close to 1 percent.

The several deposits differ in gangue minerals and character of rock alteration, and differences have been regarded as peculiarities of the individual lodes. Mineralogic changes in depth in even the deepest mines are inconspicuous and give little indication of the zonal distribution. However, all the deposits carry minute amounts of arsenic and sulphur. The ratio of arsenic to copper ranges in the different deposits from a few ten-thousandths of 1 percent up to 0.5 percent. There is a corresponding variation in the small sulphur content, but fewer quantitative data as to sulphur are available. Deposits with similar arsenic ratios are found to have similar types of gangue minerals and rock alteration. The deposits with highest arsenic ratio are likewise highest in sulphur and are characterized by a gangue of sericite and ankerite. Those with less arsenic likewise have less sulphur and are characterized by an adularia-prehnite gangue. Those with the least arsenic are practically sulphur-free and have increasing quantities of zeolites. These types of mineralization are regarded as having

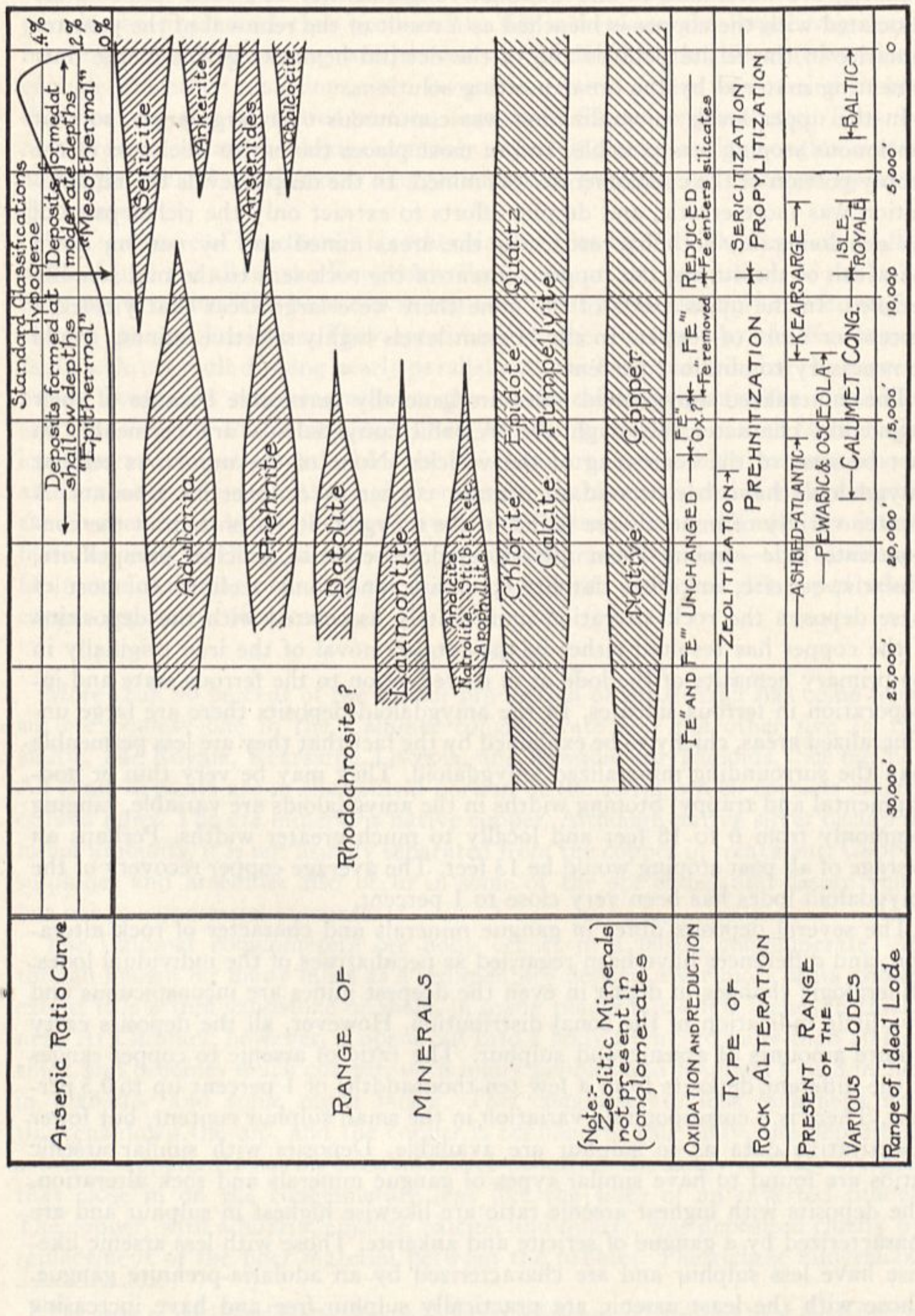

FIGURE 30.—*Zonal ranges and chemical and mineralogical features of the lode deposits of the Michigan copper district.* (After T. M. Broderick, Econ. Geology, vol. 24, p. 313, 1929.)

occurred in lower-temperature zones. The three zones grade into one another, and commercial copper occurs in all of them. In most of the mines the ratio of arsenic to copper increases with depth, and calculations based upon this rate of increase indicate that commercial copper was deposited over a distance of more than 20,000 feet down the dip of the lodes. This estimate seems not unreasonable, as mines like the Calumet & Hecla and the Quincy have already followed copper about 10,000 feet down the dip and are still in ore. Figure 30 shows the various lode deposits placed in their relative zonal position by means of their arsenic ratios. The typical minerals and rock alterations of the various lodes and zones are shown diagrammatically.

Apparently among the conditions that an amygdaloid or conglomerate should have fulfilled in order to make an ore body were the following: (1) It should have been accessible from the sources of the copper-bearing solutions in depth; (2) it should have offered a through-going solution channel—that is, it should have been continuously permeable as compared with the adjacent rock; (3) there should have been suitable restrictions to the permeable portion. All the ore bodies are in relatively permeable rocks, but apparently some sort of a barrier was necessary to prevent the solutions from spreading out and dissipating their copper content in great bodies of noncommercial grade. Solutions ascending the Calumet conglomerate, for instance, were confined by the gradually converging shale margins. Those ascending the Osceola amygdaloid were deflected under long, raking bars of tight cellular amygdaloid.

Although most of the deposits have shown a declining copper content with increasing depth, it is by no means certain that the depth factor is the explanation of the decline. There are more reasonable explanations, based on local conditions peculiar to the individual deposits. Thus in the Calumet conglomerate ore body the inverted-funnel shape means that the mineralizing work done by the solutions was distributed throughout a much larger volume of rock in the deeper levels than in the smaller portions higher up. The amygdaloid lode of the Baltic and Ahmeek mines has a higher proportion of tight trappy areas in the lower levels than in the upper levels. In the Osceola lode the ore shoot is confined to the under side of a long, gently raking bar of tight trappy amygdaloid, which acted as a barrier, deflecting the solutions ascending the lode. The deeper levels are farther removed from the confining influence of this barrier and show a lower copper content. If the Calumet conglomerate lens should show a reversal of its tendency to thicken and lengthen, becoming thinner and shorter with greater depth, the possibilities that the copper content would increase correspondingly are very good. Similarly, if the unfavorable type of amygdaloid found on the lower levels of some of the mines should give way at greater depth to the more favorable types found nearer the surface, it seems probable that there would be a corresponding increase in copper content. Thus the statement that there is a decline in copper content with depth should be qualified by recognition of the fact that the various lodes have local peculiarities which may account for the decline, and that if such local conditions should disappear at still greater depths, the copper content might increase to that obtained in the upper levels.

All the known ore shoots come to the rock surface somewhere with good copper content. There is no evidence of a leaching of copper at the surface and redeposition at depth. As explained below, however, there is reason to believe that the district may contain undiscovered deposits that do not reach the present surface, and the location of such deposits was the object of exploratory work in progress up to the time when conditions in the industry caused a suspension of all exploration.

Genesis of deposits

There are two strongly contrasting theories to account for the native-copper deposits. One is that cold oxidizing chloride waters descended from the surface for many thousands of feet by gravity or by atmospheric pressure, first percolating through hot traps and gathering up disseminated copper, then carrying it laterally and downward into amygdaloids and conglomerates, where the solutions reacted with the ferrous silicates, forming native copper and ferric compounds. According to this theory, the traps are essential as sources of copper and the chloride waters as carriers, and the deposits should be found on the upper sides of impermeable barriers.

The theory proposed by the Calumet & Hecla geologists is that underlying intrusives, which are known to exist in the Lake Superior Keweenawan, on crystallizing, gave off solutions rich in copper, arsenic, and sulphur; these solutions, expelled under enormous pressures, followed permeable amygdaloid and conglomerate channels upward, cooling and entering regions of lower pressure as they ascended; when they reacted with the highly oxidizing wall rock, their arsenic and sulphur were oxidized by the ferric iron of the lodes and their copper was deposited as native metal. According to this theory, the traps are not essential to the formation of the ore bodies. The copper did not come from them, and any other oxidizing environment would have served to precipitate native copper, just as has occurred at Corocoro, Bolivia, where there are no lava flows and native copper was deposited in commercial quantities in red sandstones. The chloride waters now found in the Michigan mines are not regarded as being necessary to explain the native copper. The copper deposits should be found underlying impermeable barriers.

Exploration

Most of the known amygdaloid and fissure deposits were found with copper showing in the outcrops. At some of them a prehistoric race had mined the rock at the surface, and the white men later "rediscovered" the deposits by cleaning out the old pits. Thus by examining the small percentage of the bedrock that is not thickly covered with glacial drift and by opening up the ancient miners' pits, the major ore bodies of the district have been found. The last commercial ore body to be discovered was the one on the Baltic lode. Since that time, about 50 years ago, many millions of dollars has been spent in diamond drilling, trenching, and underground work without discovering a new ore body. After this long period of expensive and futile exploration, what encouragement is there for further search for new ore bodies? Some of the considerations involved in exploration will be briefly reviewed.

Only a small percentage of the copper-bearing formation is not drift-covered, yet the examination of this small percentage led to the discovery of most of the amygdaloid and fissure ore bodies. Although the drift covering hampers exploration, the very fact that it is so widely present leads to the conviction that there must be undiscovered ore bodies beneath it. If the rock cropped out everywhere, there would be little chance of finding new deposits exposed at the surface after 85 years of search.

Copper deposits are known over an area of some hundreds of square miles. This is to be contrasted with other districts such as Butte, where a similar production has come from only a few square miles. Thus in this district the explorer is handicapped by the enormous areas of barren ground in the midst of which commercial deposits must be sought. On the other hand, it means just so many more square miles in which deposits may occur.

There seems to be a generally accepted notion that enormous tonnages of rock exist with a copper content just below that required for a profit. The Ashbed amygdaloid and the Allouez conglomerate are often mentioned as having been appreciably mineralized over large areas, because they are known to contain some copper at widely spaced localities. The idea that higher prices for copper would increase the reserves of commercial ore is true to some extent, but such an increase would by no means be as great as is generally believed. Experience in this district indicates that the rich deposits are large and the leaner deposits are smaller

Although mineralogic studies have been a feature of all the geologic surveys of the district, nothing very positive of a mineralogic nature has been discovered to serve as a guide in exploration. It is recognized, however, that the commercial lodes have a greater variety of minerals than the average amygdaloid. The recognition of the approximate position of a prospect in the zonal range by means of the arsenic ratio and characteristic gangue minerals is, of course, an advantage.

A study of the surface geology is an inexpensive and necessary first step in exploration. The chances that any new deposits can be found by inspection of surface outcrops are exceedingly remote. Where the overburden is thin enough trenching and test pitting may be used to advantage.

Where any considerable depth of overburden exists diamond drilling is the most satisfactory method of determining the general geologic conditions, such as kinds of rocks and character and position of lodes. But it is not a reliable method of determining copper content, because of the very erratic distribution of the metal. The drill may encounter local bunches of copper in a worthless lode; on the other hand, in going through ordinary amygdaloid lodes of commercial grade, it is more than likely to miss the copper. Where the copper is more uniformly distributed, as in a sandstone or conglomerate ore body, the drill has a better chance to obtain a good sample of the copper content.

It was hoped that geophysical methods would be useful in the search for new deposits, but after a variety of electrical and magnetic methods had been tried out the results were found to be disappointing. The copper is so small in amount and so widely disseminated that its effect on electrical methods is little or no greater than the effects caused by differences in thickness and character of overburden and differences in character of bedrock. So far as magnetic methods are concerned, there are no known magnetic effects connected in any way with the ore bodies. Various geophysical methods, however, are somewhat useful in preliminary geologic work, such as laying out diamond-drill locations. For such work the dip needle has so far been found to be satisfactory, as it affords a rapid method of determining the main features of the geologic structure. It could have been used to considerable advantage in earlier years in some places where the local strike was not so well known as it is at present. Recently the Michigan Geological Survey has taken dip-needle readings over large areas of the copper-bearing formation for the purpose of testing this method in mapping the details of stratigraphy and structure in the district.

After the diamond drill or any other method has done all that it can in determining the general geologic features of an area, underground openings must be made to locate ore and to determine its grade. For every major deposit there are scores of erratic and local patches of mineralized rock scattered throughout the Keweenawan series, not only in Michigan but in the entire Lake Superior district. Only by opening up the lodes for hundreds or thousands of feet can it be determined whether or not the mineralization was of commercial importance; and large-scale mill runs are necessary to determine the grade, as the erratic nature of the mineralization makes ordinary sampling methods useless.

It is apparent that the ore bodies are determined by favorable conditions of a purely local character, such as access from the source of solutions in depth, through-going permeability, and suitable restrictions by barriers. Even though a given bed fulfills all the necessary conditions and has an ore body at one place, it would be purely a coincidence if that same bed should be found to have the necessary conditions at another place. Nevertheless, much of the exploratory work hitherto done in the district has been based on the idea that a bed having an ore body in one place is likely to have others.

In recent years the method of exploration adopted by the Calumet & Hecla Consolidated Copper Co. has been to crosscut those parts of the series that, by diamond drilling or other means, are known to have exceptionally numerous beds of a favorable physical character. These crosscuts are driven from conveniently located places in the mines or from shallow shafts sunk for the purpose. This method has an advantage over the old one in that numerous favorable beds are crosscut instead of only one bed being explored. Any individual bed, although perhaps having an ore deposit many miles away because of favorable conditions at that place, may be of a most unfavorable character at the place being explored. Even this improved method is unsatisfactory, however. It lacks definiteness in that specific places of outstanding attractiveness are not indicated; and furthermore, some of the known ore bodies are in the only favorable bed for hundreds of feet in either direction. Therefore the policy of exploring in belts of dominantly favorable amygdaloids would fail to find such ore bodies as occur in isolated favorable lodes.

Geologic studies during the last few years indicate more specific places to explore. A study of the relationships of lode mineralization and fissure mineralization has developed the idea that some of the fissures were mineralized by solutions that leaked away from the major amygdaloid or conglomerate channels. Especially would this be true if the lode were partly blocked by the barriers closing in more or less completely, a condition under which the solutions might be able to make their way upward above such places only by escaping through the fissures intersecting the lode. In the few places where such a relation between fissure and lode seems to exist, the copper does not continue on the fissure right down to the feeding lode. There is a gap of hundreds of feet of fissure vein which contains little copper. This situation leads to speculation as to whether or not the old fissure veins that were so prominent in the early history of the district as producers of mass copper may not have been merely the vents for the solutions that escaped from some large amygdaloid or conglomerate ore body at greater depth. These fissure deposits were worked to comparatively shallow depths, where they became too lean to mine; yet they continue downward as strong fissure veins filled with gangue minerals of a type which indicates that they are still high up in the zonal range over which copper is deposited in this district. In order to test this idea, two of the old fissure-vein mines, the Cliff and the Phoenix, were unwatered, and an attempt was made to find a major amygdaloid or conglomerate deposit that might have acted as a feeder for the fissures. This work was suspended before completion, owing to unfavorable conditions in the industry. The chief elements of uncertainty, of course, are whether these particular fissures have such a relationship to a lode-solution channelway and, if so, whether that lode has been commercially mineralized and whether the gap between the bottom of the ore in the fissures and the lode ore is short enough to be bridged by a reasonable expenditure.

Future outlook

The district as a whole is classed among the high-cost producers, principally because of the low average content of copper in the ore and the great depths from which the material must be mined at most of the properties. During recent years new deposits and high-grade extensions of known deposits have been found in various parts of the world. Many of these new deposits enjoy advantages that seriously affect the future possibilities of the higher-cost producers of the United States. Among such advantages are their high grade, their shallowness, their content of other valuable metals, such as gold, nickel, and platinum, enabling their copper content to be regarded as an almost vanishingly low-cost byproduct, and what amounts in some regions to government subsidies. The high-cost producers of the United States regard their chances of competing in the foreign market under such conditions as hopeless. They base their hopes for the future on the exclusion of the excess low-cost foreign copper from the United States and a resumption of domestic consumption to a degree that will allow them to exist. This district needs a higher price for the product and new deposits if it is to continue. Otherwise, after a few years of drawing pillars, mining the richer spots in the shallower mines, and reworking the richer tailings of earlier days, the copper mining of Michigan will be a thing of the past.

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There are a great many publications that deal with the geology of the Michigan copper district. The following are a few which present the geologic setting and also some of the changes in ideas as to the origin of the deposits.

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Copper in Missouri[1]

By Josiah Bridge
United States Geological Survey, Washington

Copper was discovered in Missouri prior to 1835 and has been mined sporadically ever since. The production since 1880 has averaged about 200,000 pounds a year, with a maximum in excess of 1,500,000 pounds.

The deposits are small, and all occur in the Cambro-Ordovician limestones and dolomites of the Ozark region, mostly near the underlying pre-Cambrian. The ores are chiefly chalcopyrite and chalcocite, with less malachite and rare azurite and cuprite.

The productive deposits may be grouped, in order of their present output, under three headings:

1. Copper sulphides as byproducts in the disseminated lead deposits of St. Francois and Madison Counties.
2. The unique and highly complex copper, nickel, cobalt, and lead deposit at Fredericktown, in Madison County.
3. The scattered occurrences of chalcopyrite, chalcocite, and malachite in Ste. Genevieve, Shannon, Crawford, and Franklin Counties, which have been mined primarily for copper.

In the lead deposits of southeastern Missouri (1, 2) the ore has been rather finely disseminated throughout the lower Bonneterre dolomite (Upper Cambrian). Associated with the galena are small amounts of chalcopyrite, more abundantly in the southern part of the district, particularly around Mine La Motte (3). In one of the workings in this locality the chalcopyrite was more abundant than the galena (1, p. 659), although minute amounts of chalcopyrite are probably present in almost every deposit. Buckley gives an average figure of 0.06 percent of copper in the crude sulphide ore and 0.30 percent in the concentrates (2, pp. 195, 152, 158, 250). This is recovered partly as a middling on the concentrating tables and partly from the matte at the smelters. Practically all the copper produced in Missouri in recent years has come from this source.

The copper, nickel, cobalt, and lead deposit just southeast of Fredericktown (3, 4) resembles the deposits of the lead belt but differs in the larger percentage of copper which it contains and in the presence of cobalt and nickel. The sulphides are intermixed and present a complex problem in ore dressing. The mine produced from 1907 to 1909 and again from 1918 to 1920, when, owing largely to this mine, copper production in Missouri reached its maximum, 1,617,000 pounds being reported in 1919 and 1,512,539 pounds in 1920. The ores were treated in a mill and smelter erected near the mine. No production has been reported since 1920. Copper associated with lead and nickel occurs at other localities near Fredericktown.

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[1] Published by permission of the Director, U. S. Geological Survey.

The scattered deposits of the third class may be grouped as follows:

(*a*) The mines in western Ste. Genevieve County, about 20 miles east of the lead belt (5, 6), which furnished the bulk of Missouri copper in 1880–90. These deposits are in dolomite of early Ordovician age.

(*b*) The Shannon County mines and prospects, about 50 miles southwest of the lead belt (5, 7), formerly exploiting chiefly oxidized ores in the basal Cambrian conglomerate and of negligible production.

(*c*) The mines near Sullivan and elsewhere north and northwest of the lead belt (5, 8), associated with specular iron deposits, apparently in sink holes along the Ordovician-Pennsylvanian boundary.

All the productive deposits occur in sedimentary rocks, chiefly in sheets more or less parallel to the bedding. There are two strongly contrasting theories of origin. The geologists of the Missouri Geological Survey believe that the sulphides of copper and other metals were originally in the basal Pennsylvanian shales, which formerly covered the entire Ozark uplift, and that these sulphides were leached out during erosion of the Pennsylvanian and deposited in the underlying strata by meteoric waters. Features thought to support this theory are that most of the deposits are shallow and occur in the formation that immediately underlay the Pennsylvanian in that particular locality, and that most of them occur along unconformities, along which ground water can circulate easily.

The alternative theory, advocated by Spurr, Emmons, and others, postulates that the sulphide ores of Missouri were deposited by hot ascending solutions. The chief objections to this theory are the almost complete absence of Paleozoic and post-Paleozoic igneous activity, the absence of mineralization where such activity has occurred, and the nonpersistence of the deposits in depth.

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The Butte district, Montana

By L. H. Hart

Anaconda Copper Mining Co., Butte, Montana

Introduction

The Butte district (more accurately, the Summit Valley mining district) lies in Silver Bow County, in western Montana, about 3 miles west of the Continental Divide, at an altitude of about 6,000 feet. The complex geomorphic history of the region includes faulting of the rift-valley type, valley damming by earth movements and lava flows, lake drainage by cutting of dams, and finally widespread erosion. The topography in the immediate vicinity of Butte is somewhat mature, but that of the steep slope of East Ridge, at the eastern border of the district, is more youthful.

The climate is typical of Rocky Mountain areas of moderate altitude, with extreme winter temperatures and moderate to cool summers. Rainfall is more plentiful than in the region east of the Continental Divide.

During the 70 years of its continuous activity the Butte district has yielded copper, silver, zinc, lead, gold, and some manganese to a total value of well above $2,000,000,000. Established as a placer-gold camp in 1865 to 1875, Butte soon became a notable producer of silver and, after the completion of the railway, about 1885, of copper. Although copper has since continued to be the dominant product, zinc became important after 1910 with the advent of flotation in ore dressing. The silver production has been maintained to date, as silver is present in all types of copper ore. The history of production is outlined graphically in figure 31.

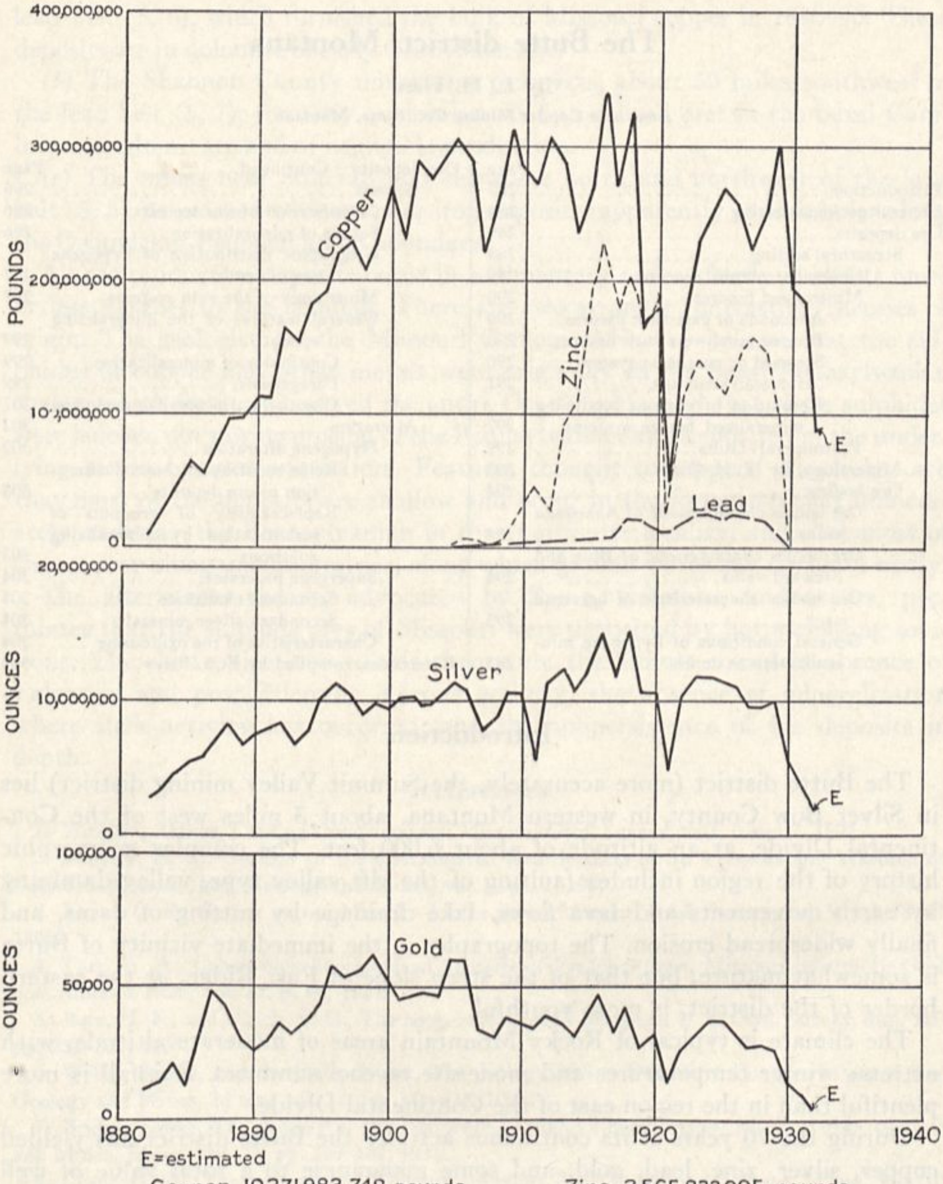


FIGURE 31.—Metal production of Silver Bow County, Montana, 1881–1932.

General geologic setting

Essentially all the copper and most of the zinc, lead, manganese, and silver ores of the Butte district have been derived from a mass of rock 2½ miles wide, 5 miles long (east-west), and three-fourths of a mile deep. This host rock, called locally the "Butte granite," is a portion of the quartz monzonitic Boulder batholith. Fractionation within the batholith during solidification produced many irregular segregated bodies of aplite, which are most prevalent in the western part of the district. After the consolidation of the batholith quartz porphyry dikes were introduced. These trend southeast and are most numerous in the eastern and central portions of the district. The fissure and vein systems were next developed. Finally, after mineralization, rhyolite dikes were intruded, a few trending east in the eastern part of the camp and many trending north in the western part. Andesite and sedimentary rocks older than the batholith crop out within a few miles of the Butte district, but these are not related to the ore deposits.

The following outline summarizes the local geologic history:

Late Cretaceous: Andesite flows.

Late Cretaceous to early Eocene: Rocky Mountain uplift immediately followed by intrusion of Boulder batholith.

Eocene: Vein formation.

Oligocene: Widespread erosion.

Miocene to early Pliocene: Rhyolite and dacite extrusion.

Late Pliocene to (?): Extensive normal or block faulting.

After its intrusion, several successive fault systems were developed in the Boulder batholith. Broadly, the earliest stresses are assumed to have acted upon a physically homogeneous quartz monzonite body, with subordinate aplite and quartz porphyry. The early faults effectively destroyed rock homogeneity with respect to all later disturbances.

Ore deposits

Structural setting

General structural features

In the Butte district several distinct fault systems, each with one or more component members, have been superimposed to produce an extremely complex fault pattern. (See pl. 16.) Certain of the earlier fissures localized the ore, and postmineral faults offset the mineralized veins. A very complete analysis of these structural features was summarized by Sales (20) in 1914. The later extensive development work substantiates Sales' conclusions, in which the faults are classified as follows, in order of age:

1. Anaconda or east-west system, comprising the oldest known fractures.
2. Blue system, the earliest fault fissure.
3. Steward system.
4. Mountain View breccia faults.
5. Rarus faults.
6. Middle faults.
7. Considered as a local feature, the Continental faulting may be regarded as a seventh separate period of fissuring.

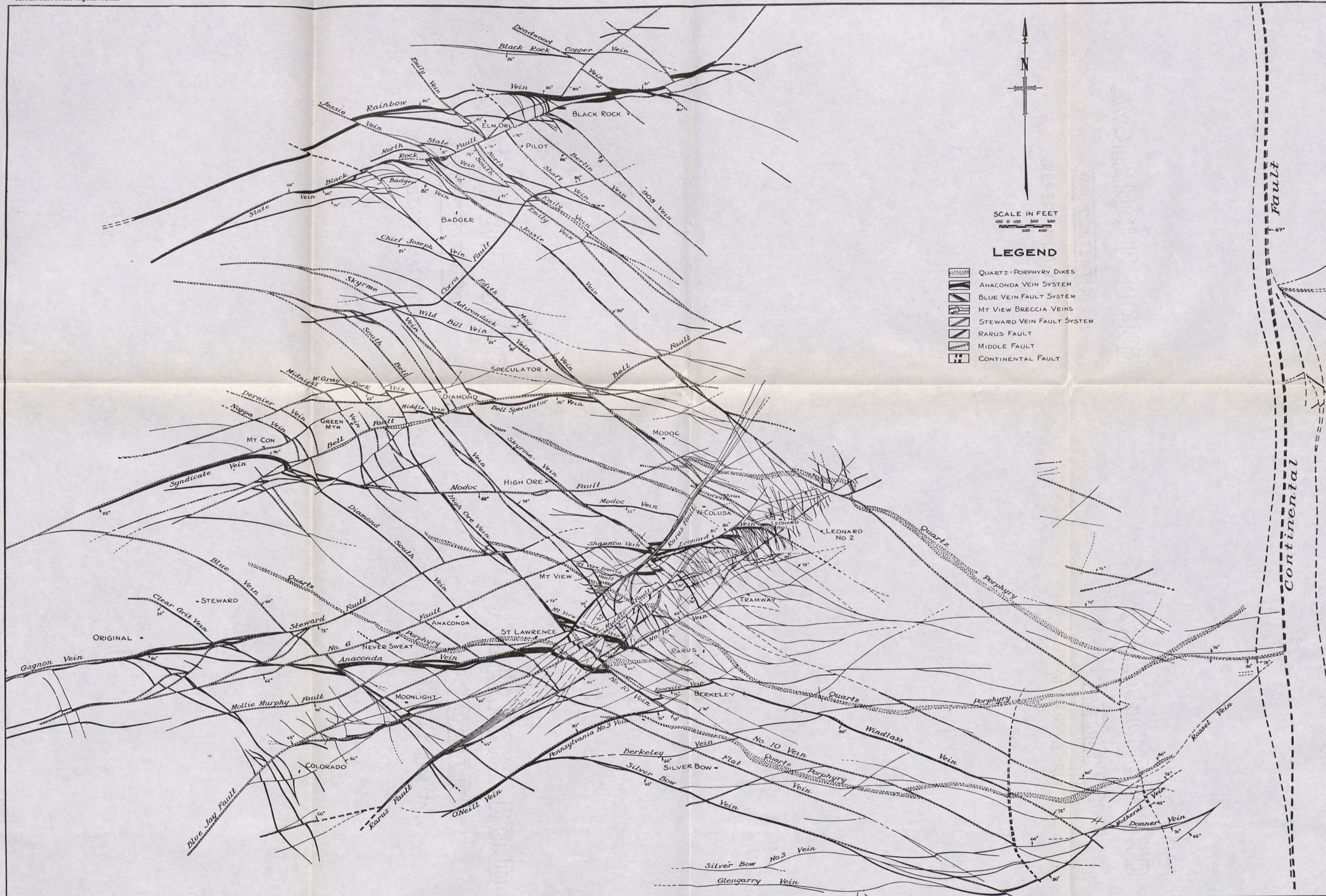
The first three of these fault systems are mineralized fissures; the others are postmineral.

Mineralized fissures

Anaconda or east-west fissures.—The earliest of the mineralized fractures trend west to southwest and generally dip steeply south. In the northern part of the district they dip steeply north in the upper levels but steepen in depth and finally dip south. These fissures are characteristically free from attrition clays or crushed wall rock. They are irregular in strike, and locally parallel, sympathetic fractures occur. En échelon breaks and complex internal cross fractures are common. These features suggest failure by tension without lateral displacement along the fractures. A unique feature, described later as "horsetail structure," appears to be an extreme phase of cross-fracture development common in east-west veins. The most productive veins of the Anaconda system are, from north to south, the Rainbow-Black Rock, the State-Badger State, the Syndicate-Mountain Con, the Original-Steward-Anaconda-St. Lawrence, and the Black Chief-Travona-Emma.

Blue or northwest fault fissures.—The members of the Blue fault system strike generally northwest and dip steeply southwest. They are strike-slip faults in which the northeast segment has moved to the northwest with reference to the southwest segment. The movement was almost entirely horizontal and in places reached a maximum of 300 feet. The Blue veins are fairly uniform in strike but show many variations in dip. They contain thick fault clays accompanied by crushed granite. The Blue faults cut and offset members of the Anaconda system. Rarely, in the lower levels, Blue faults that approach Anaconda veins at a low angle may develop strike faults along the preexisting structural weakness in Anaconda veins. The above-described local en échelon gaps in Anaconda fissures are favorable sites for Blue vein faults. The resulting apparent offset of the Anaconda vein is greater than the actual displacement. The maximum displacement on Blue fault veins is near the surface, and although the change is slight, it is evident that displacement decreases with depth.

Steward or northeast system.—Steward faults strike northeast and dip steeply south. Although less numerous, they resemble Blue faults except that in most members the vertical component of movement is the greater. Steward faults cut and displace the Blue and Anaconda veins. As they are thus superimposed on two sets of preexisting zones of weakness, much of the host-rock homogeneity had probably been destroyed prior to their development. This may account for their being commonly strike faults along Anaconda veins. The true premineral displacement along Steward faults is in many places masked by subsequent strike faulting. There is a strong suggestion that the stresses producing the Steward fissure faults were the final, almost completely adjusted forces that produced the Anaconda and Blue fissure sets. Thus, the development of a very subordinate set of Steward fissures was capable of completely adjusting the compressive stresses and marked the change from compressive deformation to relaxational settling. Probably the earliest relaxational settling occurred along the already existing Steward zones of weakness, as many unmineralized portions of Steward fissures are distinctly normal faults of postmineral age.



HORIZONTAL SECTION OF THE BUTTE DISTRICT, MONTANA, SHOWING STRUCTURAL RELATIONS OF THE FISSURE SYSTEMS

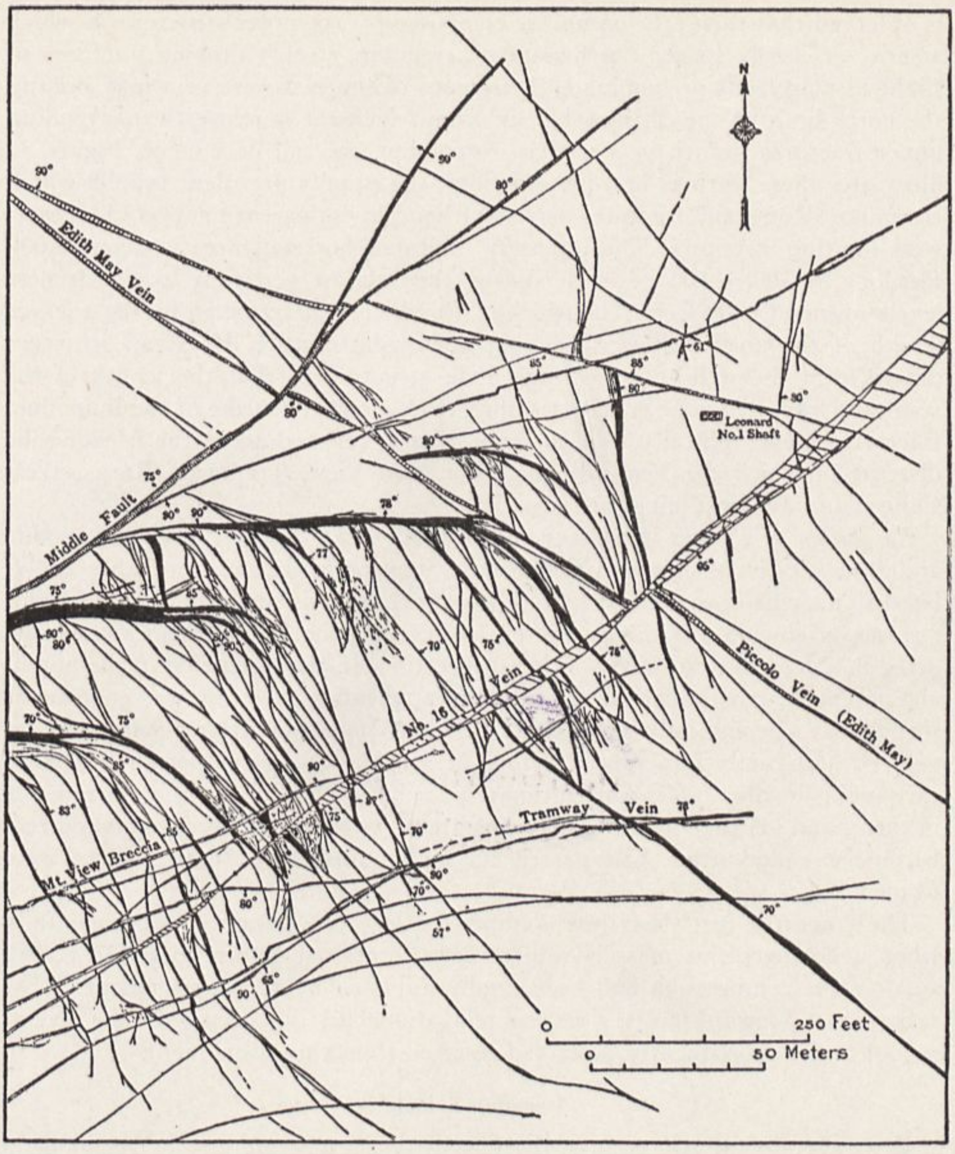


FIGURE 32.—Plan of part of the 1,200-foot level of the Leonard mine, Butte, Montana, showing transverse fissuring in Colusa-Leonard vein. This structure is typical of horsetail development and shows also fault relations. (After R. H. Sales, Am. Inst. Min. Eng. Trans., vol. 46, fig. 2, 1914.)

"*Horsetail structure.*"—East of the point where the strong Anaconda vein becomes discontinuous and approaches a faulted area, its probable continuation is represented by a series of segments, en échelon, each situated north and east of the next westerly segment. (See fig. 32.) These segments are partly obscured by a fault complex in which Blue faults occupy many of the échelon gaps, and the Rarus fault and several members of the Middle fault system are present. If, however, the area is visualized as it existed before Rarus and Middle faulting, it is observed that each échelon unit is composed of a complex structure in which a series of closely spaced northwestward-trending, steeply dipping fractures of slight displacement predominate. A segment of the east-west vein may occupy the north limit of one of these blocks, from which the northwestward-trending minor fractures branch in a pattern resembling the tail of a horse. Figure 32 illustrates these features but does not show the equally prevalent type in which the minor "horsetail" fractures persist without any apparent relation to an east-west limiting structure. The intensely fractured horsetail area is about 2,000 feet long by 300 to 500 feet wide and extends almost vertically to the deepest levels opened (3,400 feet). The width of this zone is determined by the average length of the northwestward-trending horsetail structure. Horsetail structure differs from the well-known stringer-lode structure in that the length of the resultant fractured zone is across rather than along the strike of the individual fractures. Geographically, the horsetail area is referred to as the Meaderville district, in which the Pennsylvania, Mountain View, Tramway, Rarus, West Colusa, and Leonard mines are situated.

Resolution of stresses producing mineralized fissure systems.—The Anaconda and Blue sets of fissures and the earliest Steward fissures are probably all related to a single diastrophic event. Theoretical analysis suggests that the major stresses producing the fissure system were rotational (counterclockwise) and acted in a general northwest-southeast direction. In the discussion of the mineralizing epoch, it is indicated (1) that the application of stress was continuous throughout a geologically short time, (2) that Anaconda fissures were well developed and partly mineralized before Blue faults became important, (3) that early veins in Blue faults were ultimately strike-faulted by the final movements in them, and (4) that the Steward veins are probably relatively less mineralized, because ore deposition had passed its maximum before these fissures were formed.

The fractures just described conform with those obtained experimentally when a homogeneous mass is subjected to rotational deformation (23, p. 46).

After the compression had been finally adjusted by the development of the subordinate Steward faults, a general relaxational settling occurred. The several sets of faults subsequently described resulted from this adjustment.

Postmineral faults

Postmineral faults have greatly affected the cost of mining in the district, and a complete understanding of them is essential in mining, but inasmuch as they have no importance in ore localization or genesis, only their general features are reviewed here.

Sales (20, p. 22) states that the Mountain View breccia veins were probably not all contemporaneous but that some were formed as late as the Middle faults. It is not now practicable to assign these breccia-filled veins to any definite period. They are economically unimportant.

The Rarus fault system is named after its most prominent member, which strikes N. 45° E. and dips 45° NW. The displacement, which is normal, approaches a maximum of 350 feet. The movement is usually distributed along a large number of faults between the limiting footwall and hanging-wall breaks, so that the broken zone ranges from 10 to more than 200 feet in width.

Members of the Middle fault system strike N. 70°–80° E. and dip steeply south. They are normal, with dominantly vertical displacement, which in a typical member, the Poser-Black Rock fault, is about 200 feet. The horizontal component is almost negligible.

The youngest faults recognized in the district are classified as the Continental system. They are normal faults, strike north, and dip west. The chief member, the Continental fault, with a vertical displacement of perhaps 1,500 feet, is near the east boundary of the Butte district, at the base of East Ridge. No pronounced faults of this system occur within the central part of the district.

Rhyolite dikes exposed in relation to Steward faults are later. Although not yet proved, recent disclosures in the eastern part of the district suggest that at least some rhyolite dikes may be later than the Middle faults. The rhyolite is probably earlier than Continental faulting, as a fault of the Continental series definitely offsets a rhyolite dike near Rocker, west of Butte.[1]

Mineralogy

By M. H. Gidel

The chief copper minerals of the Butte ores, named in the order of relative abundance, are chalcocite, enargite, bornite, chalcopyrite, tennantite, tetrahedrite, and covellite. Of the oxidized products, chrysocolla, malachite, cuprite, and native copper are the most common, but these have added little to copper production in the district. The gangue minerals are principally quartz and pyrite, occurring in about equal amounts. Sphalerite is abundant in the intermediate and border zones of the district. Locally it is the predominating constituent of the vein filling, as in the Black Rock, Emma, and Orphan Girl mines. In the Emma mine commercial rhodochrosite ore bodies border the main zinc ore shoot on the west.

Chalcocite occurs in two forms—the primary massive steel-gray variety, found in veins below the oxidized zone to the deepest workings (4,100 feet) in the camp; and the earthy or sooty variety, confined to those portions of the veins immediately below the oxidized zone to a maximum depth of 1,000 feet. Where the latter variety occurs with primary chalcocite it is distinguishable by its soft sooty character.

Minerals rarely found in the copper veins are galena, rhodochrosite, fluorite, barite, calcite, and hübnerite. A bronze-colored mineral containing copper, arsenic, antimony, and tin has been found in some of the veins in the east end of the district. This mineral, which is thought to be a tin-bearing tetrahedrite, has been locally named "colusite."

In the outer portion of the district the characteristic minerals found are sphalerite, galena, rhodochrosite, ankerite, and rhodonite. Quartz, pyrite, and manganese minerals finally form the chief constituents of the gangue. Sphalerite is locally present in notable amounts.

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[1] Gidel, M. H., personal communication.

Ore bodies

Three main types of ore bodies are found in the Butte district, characteristic respectively of Anaconda veins, Blue or Steward veins, and horsetail fissuring. The Anaconda veins and the horsetail ore bodies have contributed the bulk of the Butte production, and Blue vein ore bodies have been very productive. Steward veins have contributed a relatively small proportion.

Ore bodies characteristic of Anaconda veins.—Commercial ore bodies in Anaconda veins are stoped continuously for thousands of feet along the strike and downward to the greatest depths attained in mining (3,800 feet). Stope widths range between 7 and 100 feet.

Throughout the district the Anaconda veins vary considerably in physical and mineralogic character. A typical section across an Anaconda vein includes 70 to 80 percent of vein material in which residual granite texture is almost entirely absent and 20 to 30 percent of mineralized or altered granite. The ratio of quartz to pyrite in the vein material is about 3 to 2 in the more central portions of the district, but in the outer edges quartz is much more plentiful than pyrite. Pyrite exceeds 60 percent by weight of the total sulphides present.

The vein material occurs in bands composed of certain minerals or associations of minerals. These individual bands range in width from a few inches to several feet. The mineralized or altered granite, which also occurs in bands or horses within the vein banding, is in places sufficiently metallized to constitute commercial ore, especially throughout the horsetail area.

In parts of Anaconda veins not affected by postmineral faulting the ore grades rather abruptly into altered granite walls. This relation to granite walls is less common in later fault veins.

Ore bodies characteristic of Blue and Steward veins.—In contrast to ore bodies of the Anaconda veins, those of the Blue and Steward fault systems are characteristically discontinuous and confined to irregular ore shoots. The gaps between ore shoots are practically barren and commonly great. In these barren portions the fissure zone is traceable by strong, continuous fault gouge. The veins in the ore shoots resemble the Anaconda veins mineralogically but differ markedly in that the replacement and alteration of the granite was usually confined within definite limits determined by selvage clays. The mineralized portion, which may replace earlier fault clays, is locally distorted by postmineral faulting. Disseminated deposits in the walls along Blue or Steward veins are rare.

Ore shoots in Blue veins have apparently been localized by several different causes. Many are at places of curvature in the fissures. As, in the Blue veins, the northeast or footwall segment moved nearly horizontally to the northwest with reference to the hanging-wall or southwest segment, all points where the veins take westerly or left-hand flexures appear favorable to localization of ore shoots. At these points wall pressures must have been reduced and permeability to solutions increased. However, commercial ore shoots were formed not where these conditions are extreme but in the more confined end zones fringing the wide permeable zone. Conversely, in areas of right-hand flexures maximum compression operated and the access to mineralizing solutions was less favorable. Ore shoots in straight horizontal portions of these veins may have been caused by the damming effect of selvage clays or by flexures in the vertical section, which are known to be numerous.

Ore bodies characteristic of horsetail area.—Typical horsetail ores differ from those of Anaconda veins mainly in the greater proportion of mineralized granite contained. The complex minor fractures in the horsetail area have increased the permeability and thereby made possible the extensive mineralization of the granite.

Ores from the horsetail area are mixtures in varying proportions of (1) vein material of Anaconda type, (2) granite mineralized by a complex network of minor copper-bearing fractures (many visible only under the microscope), and (3) granite in which the copper minerals are thoroughly disseminated. On the basis of alumina content, it is estimated that more than 50 percent of the horsetail ore mined in 1931 was material of types 2 and 3.

The horsetail area was above described as 2,000 feet long by several hundred feet wide. Not all of this area contains ore, but many commercial ore bodies or ore shoots occur within it. Many stopes on these ore shoots trend N. 20° W., conforming to the horsetail or branching structure. Other stopes are on segments of east-west veins, and still others include combinations of the two. Individual stopes may be 400 feet or more long and 200 feet or more wide and extend many hundreds of feet vertically. According to a rough estimate the horsetail areas already stoped on the 1,600 level exceed 50 percent of the total horsetail zone. Material of this type in the Tramway, Rarus, Leonard, Mountain View, and West Colusa mines is one of the largest resources of the district.

General conditions of hypogene mineralization at depth.—Butte is preeminent as a producer of high-grade copper ores from fissure veins. In its early history, when the remarkably rich supergene ores were disclosed immediately below the oxidized and leached zone, predictions were made that only low-grade pyritic ores would be found below the secondary chalcocite deposits. This opinion persisted until it was recognized that secondary chalcocite gave way, generally at about the 1,000-foot level, to equally rich primary chalcocite. The hypogene chalcocite has since been found in large quantities to the greatest depths yet developed. Deep developments also demonstrated that the commonly associated hypogene minerals bornite, enargite, and, to a lesser degree, chalcopyrite persist in remarkable richness at increasing depths.

It has likewise been demonstrated that many large ore bodies exist whose upper limits of commercial ore were hundreds of feet below the surface; indeed, many deposits are of commercial grade only below depths of 2,000 to 3,000 feet.

Another significant observation applies to veins in which large ore shoots were mined in the upper levels but which were considerably lower in grade at a particular horizon, often at about the 2,000-foot level. Deeper development below these leaner zones has shown that the copper content increases as depth is gained. For example, on the 2,000-foot level of the Mountain Con mine, on the Syndicate vein, the ore shoot is about 1,000 feet long and contains only 3 to 3.5 percent of copper, but on the 3,500-foot level, the deepest level of the mine, this ore shoot has increased to a length of 3,000 feet with limits not yet fully determined, and the copper content averages 16.5 percent and the silver 5.4 ounces to the ton.

The remarkable persistence of chalcocite ore bodies with associated primary minerals to the deepest levels yet opened in all parts of the copper-producing area of the Butte district is of more than ordinary geologic interest and portends well for the future.

Genesis

Classification of the deposits

According to Lindgren (24, pp. 694–695) the Butte district is typical of the pyrite-enargite division of mesothermal copper deposits. In a district so extensive it would seem not unlikely that local areas might exist in which either hypothermal or epithermal characteristics begin to appear. It is significant, therefore, that such minerals as pyrrhotite, magnetite, specularite, tourmaline, apatite, garnets, spinels, brown and green micas, and topaz, which are generally

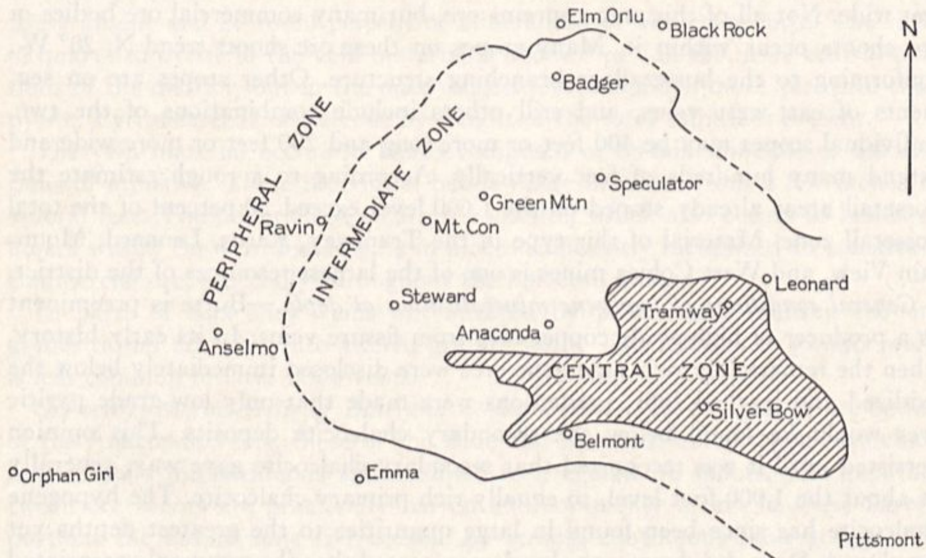

FIGURE 33.—Plan at altitude of 4,600 feet showing general zonal arrangement of ore minerals at Butte. (Revised after R. H. Sales, Am. Inst. Min. Eng. Trans., vol. 46, fig. 7, 1914.)

diagnostic of hypothermal deposits, are almost unknown at Butte. Similarly, true epithermal relations do not exist in the outlying peripheral areas, although the valuable silver-bearing galena-sphalerite ores and, rarely, subordinate chalcopyrite in a gray quartz (almost chalcedonic) gangue are believed to represent rather extreme outer mesothermal conditions. The zonal distribution of minerals in Butte conforms to the normally expected gradations within mesothermal limits, the central or copper zone representing the deepest-seated portion and grading outward into the zinc-lead-manganese zone.

Source of mineralization

The mineralization was related to the final consolidation of the late Cretaceous Boulder batholith and probably followed closely the injection of quartz porphyry. The major point of ingress is believed to have been local, as is indicated by the centralized productive area and the lateral and vertical zonal distribution of minerals in the district. Zonal mineral distribution vertically as well as horizontally supports the belief that the mineral solutions migrated upward and outward from a center of origin. These conclusions are supported by the facts discussed below.

Geographic distribution of hypogene ore minerals

The primary zoning at Butte was first described by Sales (20, p. 58). Certain mineral relationships or associations characterize zones which he designated central, intermediate, and peripheral. This zoning is both vertical and horizontal but may be best described with respect to a plan view. Sales made a plan map of the 1,600 level in Butte, showing the approximate boundaries of these zones as determined by development work at that time. Subsequent disclosures have not materially altered his mapping except to add more information in certain areas not adequately developed at the earlier date. Figure 33 is a revised zonal distribution map.

These zones are gradational, but in general they advance outward from the central zone as depth is gained, thus implying some lateral movement of solutions, although apparently the greater component of migration was vertical rather than horizontal. The zonal boundaries in the outer portions of the district are nearly vertical, but in the central area they flatten to nearly horizontal, suggesting that solution migration was upward and outward from the probable center of introduction.

The more abundant ore minerals of the central zone are chalcocite, bornite, and enargite. Subordinate covellite and locally a little tetrahedrite may be present. The ore minerals characteristic of the intermediate zone include all the copper minerals of the central zone and, in addition, subordinate amounts of chalcopyrite and tennantite. Sphalerite and small amounts of galena and rhodochrosite occur increasingly as distance is gained from the central zone. The principal minerals of the peripheral zone are sphalerite, argentiferous galena, and rhodochrosite, with rarely rhodonite and chalcopyrite. Silver enrichment is common in the peripheral zone. In outlying portions of the peripheral zone the mineralization brought in sugary quartz or dull-gray quartz with ankerite and locally small amounts of pyrite and arsenopyrite. Many of the veins are very large, 100 feet or more in width, but contain insignificant amounts of valuable metals. Calcite and barite are locally present in notable amounts.

The relative amounts of the principal minerals in the different zones are indicated graphically on figure 34.

Mineralogy of the vein systems

If separate mineral-distribution maps of each of the three vein systems are superimposed upon one another, the zonal boundaries of the Anaconda system at a particular level are seen to conform closely to those of the Blue vein system at a somewhat lower level. In general, however, the minerals of the different veins are similar within any given area.

According to Sales (20, p. 62), the distinctions between the systems, where recognizable, are in relative quantities of minerals present or in physical

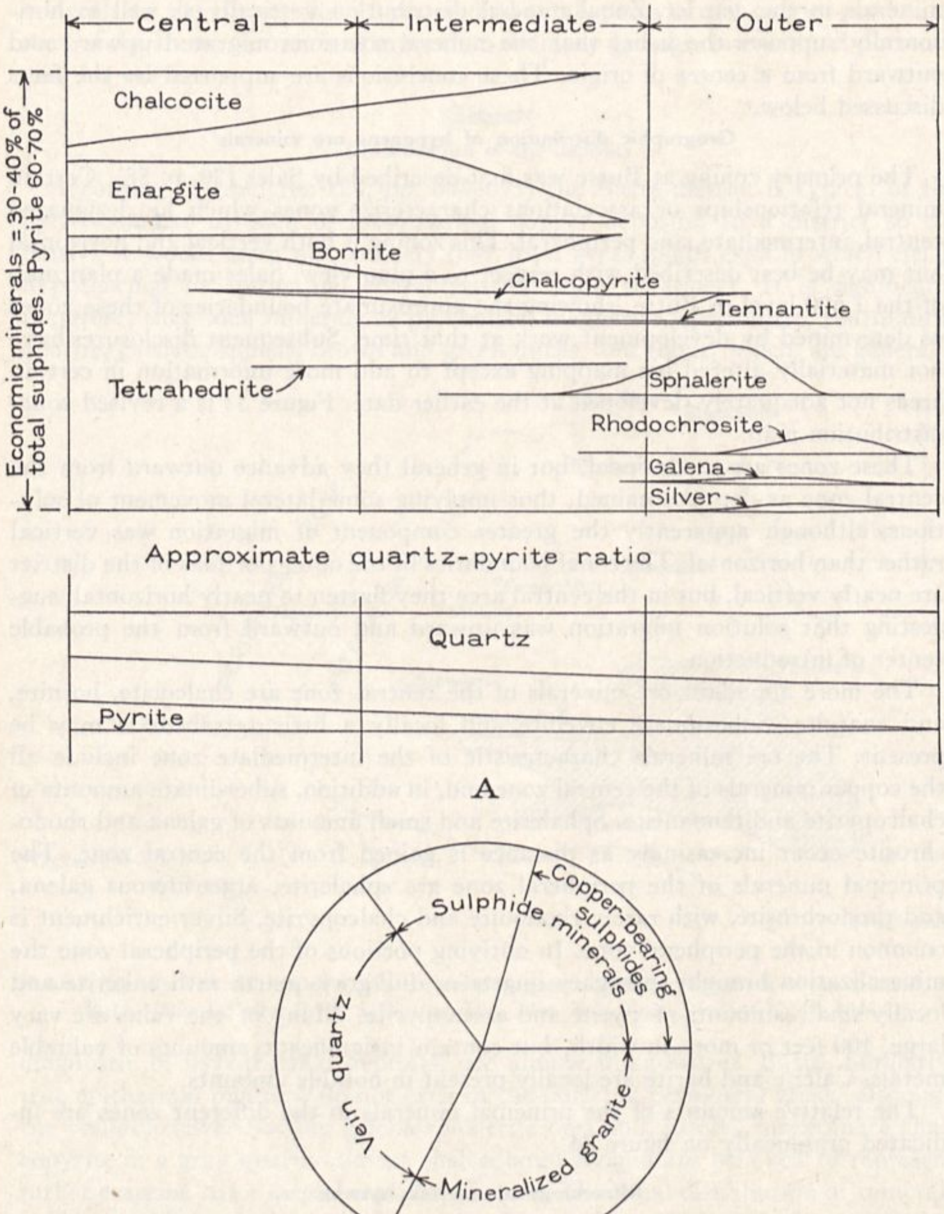

FIGURE 34.—A, Zonal mineral distribution at Butte. B, Approximate composition of material shipped as ore from Butte to reduction works in 1931 (proportions determined by calculation).

features such as texture. The variation in mineral composition of veins is a matter of geographic position rather than geologic age.

Apparent variations from the above generalization are locally not uncommon, but the same factors that produce the irregularities in mineralization within a single vein may probably account for intervein irregularities.

General features of the mineralizing epoch

Continuity of mineralization.—Inasmuch as the mineralized fissure systems are of distinctly different ages, and the mineralization in the veins within a small area is similar, the ore-bearing solutions were probably derived from one general source and were introduced continuously throughout the relatively short geologic time required to develop the Anaconda, Blue, and Steward fracture systems. Detailed mapping of numerous places where Anaconda veins are cut and offset by Blue fault veins indicates (1) that Anaconda veins were mineralized, at least in part, prior to the Blue faulting; (2) that where Anaconda veins are cut by mineralized Blue faults, the mineralization of the Anaconda veins terminates abruptly against that of the Blue faults; and (3) that Blue faults were mineralized, at least in part, before fault movement within them had ceased.

Although veins of the Steward system are somewhat later than those of the Blue system, their mineral content is similar, but the Steward veins show a much less intense mineralization. They contain relatively few commercial ore bodies, and evidently mineralizing activity had dropped notably below its maximum before the Steward faulting was well advanced.

Another feature suggesting a single, major mineralizing epoch is the especially noticeable mineralization "overlap" in the outer transitional limits of the intermediate mineral zone. Had the mineralizing activity been discontinuous, the mineral overlap would probably have been much more extensive.

Paragenesis.—Most students of the paragenetic relations at Butte have confined their attention to the intermediate zone. It has been suggested above that this zone is characterized by mineral overlap, in which the normal copper minerals of the central zone have encroached upon the zinc-lead-manganese minerals of the peripheral zone, so that here the true mineral sequence as applied to the mineralizing system as a whole is difficult if not impossible to determine. However, the mineral sequences of the central and the peripheral zones may be separately determined. These sequences are presented graphically in figure 35. The relations determined in the intermediate zone are used to correlate the time relations of the two series.

The most significant conclusion from this diagram is that the minerals of the copper series in the central zone were probably being deposited successively, contemporaneously with the zinc-lead-manganese minerals that were being successively deposited in the peripheral zone. The evidence supporting this conclusion is summarized as follows:

The minerals of the central zone include quartz and pyrite with enargite, bornite, chalcocite, and rarely subordinate amounts of covellite and tetrahedrite. The minerals of the peripheral zone are quartz and pyrite with sphalerite, galena,

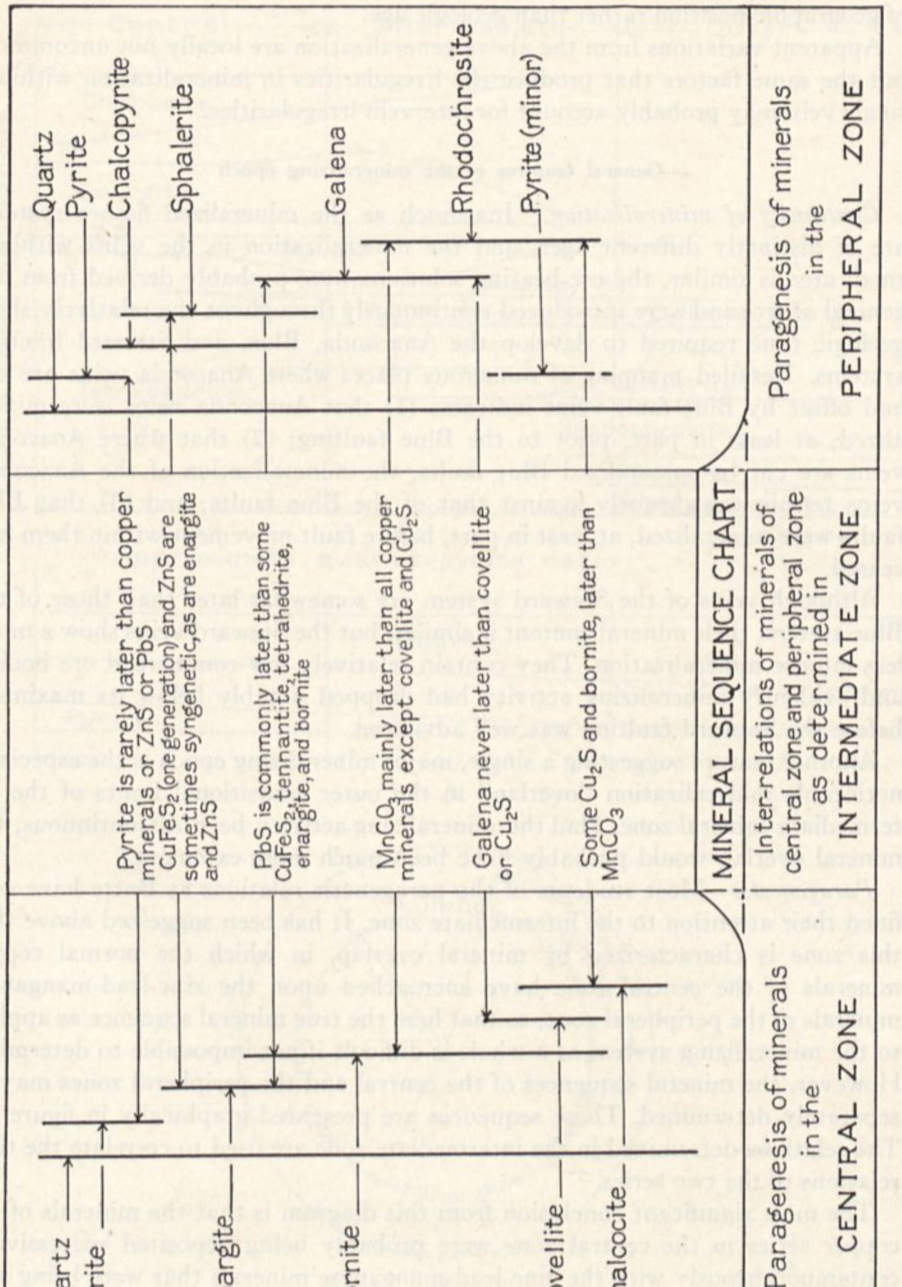

FIGURE 35.—Chart of mineral sequence at Butte.

and rhodochrosite. The paragenesis of each group is clear when observed at points outside the overlap zone.

Among the minerals of the central zone quartz has been deposited more or less continuously through the entire series. Most of the pyrite was deposited before the copper minerals. The copper series is complex and may exhibit some "conversion," or reversible relations. However, in general, enargite was the first copper mineral to develop, followed closely by bornite, which is in places syngenetic with subordinate covellite and tetrahedrite. Hypogene chalcocite closed the cycle. This suggests a tendency toward the deposition of copper minerals progressively higher in copper content.

The mineralization of the peripheral zone also began with quartz and pyrite deposition, most of the pyrite being older than any notable introduction of sphalerite. Chalcopyrite is closely associated with sphalerite. Galena followed sphalerite, and rhodochrosite was later than all the other minerals of this group, except possibly a minor generation of pyrite.

In the outer intermediate zone the mineral relations in the overlap zone show that an early chalcopyrite generation and some enargite are syngenetic with sphalerite. As a rule, however, enargite and all other copper minerals are later than sphalerite. Although galena is only sparingly present, it is younger than the early copper minerals. Some bornite may overlap galena. Similarly, where observed in intimate overlap relation, covellite and chalcocite are later than galena. This relation is entirely the result of encroachment by copper minerals upon galena and does not represent a true paragenetic relationship. Similarly, rhodochrosite is commonly replaced by all copper minerals, except covellite and chalcocite.

The foregoing observations suggest that quartz and pyrite were being deposited throughout the central, intermediate, and peripheral zones simultaneously at the beginning of the mineralizing epoch. Pyrite deposition terminated abruptly in all places; in the central zone it was followed by enargite, and in the peripheral zone it was followed by sphalerite and subordinate amounts of chalcopyrite. Overlap relations suggest that enargite and sphalerite were being deposited at the same time from the same mineral system, but predominantly in their respective zonal positions.

Sales (20, pp. 87–89) states that there is no evidence to support and much to contradict the hypothesis that the so-called "manganese-silver or zinc veins" belong to an epoch distinct from that in which the copper veins were formed. During the later stages, when the Blue and Steward ores were formed, enargite, bornite, and chalcocite were deposited in large quantities in veins of all ages within the central and intermediate zones.

Similarly, galena is younger than sphalerite in the peripheral zone. As seen in the intermediate overlap zone, some enargite, tetrahedrite, tennantite, a second generation of chalcopyrite, and bornite were being successively deposited while sphalerite and later galena were being deposited in the peripheral zone. Rhodochrosite, which follows galena in the peripheral zone, was deposited simultaneously with tennantite, tetrahedrite, second-generation chalcopyrite, bornite, early covellite, and chalcocite in the intermediate zone. Probably some bornite, covellite, and much chalcocite were deposited in the central zone after the rhodochrosite deposition had ceased in the peripheral zone. Chalcocite closed the economically important mineral cycle.

The relations set forth above outline the general conditions at the extreme geographic limits of the mineralization but do not account for the conditions producing the overlap zone. These conditions are best visualized by assuming that the transition between the central-zone minerals and the peripheral series first occurred at a position deep in the intermediate zone. As mineral solutions continued to circulate through the vein system, for some reason, possibly a rise of temperature, the transition zone moved outward toward the peripheral zone, so that copper minerals of the central zone encroached upon sphalerite, galena, and rhodochrosite. All observations indicate that there were no important reversals in the outward migration of this transition zone and that sphalerite, galena, and rhodochrosite have only rarely encroached upon the copper-mineral series. This is contrary to the general "resurgence" principle appealed to in many districts.

Chemistry of mineralizing solutions.—The chemistry of the mineralizing solutions was comprehensively discussed by Sales (20, pp. 82–91), whose conclusions may be summarized as follows:

The general relations between the several ore types and the varieties of alteration of the granite suggest that under conditions of high alkalinity and high temperature and pressure the vein minerals first deposited were principally pyrite and quartz. That these conditions prevailed early in the mineralization of fractures of all ages (except where the later fractures cut previously altered granite) is shown by the universal priority of part of the quartz and pyrite. The solutions later became less alkaline, with a corresponding increase in the proportion of hydrogen sulphide present. Iron, copper, zinc, and manganese are soluble in sodic sulphide solutions, but less so in hydrogen sulphide solutions—in fact, hydrogen sulphide in sufficient concentration precipitates these metals. The change from a highly alkaline solution to one in which hydrogen sulphide predominates was brought about through reaction between the uprising solutions and the wall rock. Chalcocite is a late mineral in the ores, perhaps because it was deposited in the Butte veins only when the concentration of hydrogen sulphide in the vein-forming solutions was large in proportion to the alkaline sulphides. Observations in the veins tend to support this view. Regardless of the geologic age of the fissure, quartz and pyrite were the first minerals formed, chalcocite one of the latest, and enargite, sphalerite, and bornite were of intermediate age.

Alteration

Alteration at Butte involves both hypogene and supergene changes in the country rock, as well as in the vein material. In the following summary the more significant relations between these processes and the localization of ore deposits are indicated.

Hypogene alteration (hydrothermal)

Sericitized and chloritized granite, the usual products of hydrothermal alteration, are very highly developed near the Butte veins. Generally the chloritized material forms a narrow marginal band enclosing sericitized rock. Although most of the granite in the Butte district proper is distinctly altered and its plagioclase is stained greenish, only a relatively small amount of intensely chloritized material is common. Sericitization is far more extensive, and throughout the general horsetail area and much of the central zone it is almost impossible to obtain a specimen that is not partly sericitized. In the intermediate and peripheral zones sericitization and chloritization are related to vein structure, and the width of wall rock affected varies with the size of the associated vein. Sericitization has been more extensive in the lower levels of all mines than in the upper levels.

Along great veins, 100 feet or more wide, in the manganese-silver area (peripheral zone), alteration of the granite extends only a few feet outward from the vein boundaries (20, p. 89).

Relation of hydrothermal alteration to ore deposits.—The time of sericitization with reference to the metallization is difficult to establish definitely. However, as pyrite is an early mineral, its wide dissemination throughout all sericitized areas is significant. Although little or no iron has been added in the pyritization of the granite accompanying sericitization, sulphurous solutions were essential to convert the residual iron to pyrite, indicating that sericitization was well advanced before the copper metallization.

The occurrence of disseminated isolated particles of chalcocite and bornite in some sericitized areas, commonly replacing pyrite, further suggests that the alteration had progressed considerably before the end of the copper cycle of metallization.

Sericitized rock is evidently more permeable than unaltered rock, although there has been no apparent change in volume accompanying the alteration.

Replaceability of products of sericitization by mineralizing solutions.—Where the disseminated pyrite in altered granite is replaced by chalcocite and bornite, the resultant "mineralized granite" may constitute commercial ore, as in the horsetail area and other localities.

The veins have been largely formed by metasomatic replacement of granite near permeable channelways. The replacement occurred in successive stages—first, hydrothermal alteration; second, pyritization; and third, replacement of the pyrite by copper sulphides. The resulting vein filling consists of bands of granite extensively replaced by pyrite or other sulphides and bands of almost solid sulphides showing practically no evidence of granite replacement. It is difficult to determine the process of formation of the solid sulphide bands that show no relicts of granite. It was believed that the alumina, because of its chemical inactivity, would remain approximately constant during the metasomatic replacement of granite. However, the ore shipment from the Mountain Con mine during a certain month, representing mine run from stopes more than 20 feet wide, averaged 2.8 percent of alumina (Al_2O_3), thus implying alumina displacement on a large scale.

Mineralization by filling open fissures is one possible explanation for this deficiency of alumina, but vugs are uncommon, and replacement of granite is universally the most effective factor in vein formation.

Supergene processes

Kaolinization has been surficial only and of no influence upon ore deposition. It was accompanied by oxidation and the formation of acid solutions capable of dissolving many of the hypogene sulphide minerals. Certain of the dissolved metals were redeposited under reducing conditions, forming secondary ore bodies.

Secondary chalcocite.—Sales (20, pp. 93–106), presented an exhaustive argument to show that chalcocite is a hypogene mineral at Butte. Locke, Hall, and Short (14, pp. 933–963) gave additional data obtained in a thorough microscopic study of Butte ores, confirming the conclusions of Sales.

Both hypogene and supergene chalcocite are now generally admitted to be present at Butte. The deepest point in Butte at which hypogene chalcocite has been exposed is on the 4,100-foot level of the Badger mine. Most of the secondary or sooty chalcocite occurs below the zone of oxidation and above the 1,000-foot level.

Secondary silver minerals.—Many of the silver ore bodies at Butte are supergene and related to the peripheral zone in the same way as the supergene chalcocite is related to the central and intermediate zones, although the occurrence of secondary silver is not confined to one mineral type. Argentite, proustite, stephanite, and pyrargyrite are the most abundant secondary silver minerals. There is more silver in the peripheral hypogene ores than in the central or inter mediate zones, but primary silver ores were rarely commercial, except locally in the more outlying portions of the district. Among the larger of the former silver producers are the Alice, Moulton, Glengarry, Goldsmith, Eveline, and Nettie mines.

Characteristics of the oxide zone

The oxide zone overlying the central copper area is leached and barren of ores except local concentrations of silver. In the peripheral areas the supergene silver concentrations are more extensive below the oxide zone than in that zone itself. The oxidized zone is relatively leached with respect to most minerals except sphalerite and galena, which have been to some extent oxidized in place but not enriched. Rhodochrosite was oxidized to manganite and pyrolusite, and local evidence of surficial enrichment has been recognized. Exceptionally, some oxidized silver products have been observed, notably wire silver.

Gold is enriched in the oxide zone, but as its content in the hypogene ores is very low, commercial deposits are rare. To some extent the eroded enriched deposits of gold have been mechanically reconcentrated in the nearby gulches as placer deposits, whose discovery led to the early establishment of the Butte camp.

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The copper deposits of Ely, Nevada

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Introduction

Ely is the most productive mining camp of Nevada. Beginning as a gold-silver-lead district with small production, it achieved fame on the discovery of large deposits of low-grade disseminated copper ores. In fact, it was one of the earliest of the so-called "porphyry coppers" to be operated and is today one of the great copper camps of the world. Copper production started in 1908, and to date the district has yielded 1,800,000,000 pounds of copper, most of which has come from the mines of the Nevada Consolidated Copper Co., which also owns the reduction plants at McGill, Nevada, with a daily capacity of 20,000 tons of ore. The only other copper producer is the Consolidated Copper Mines Co., whose ore is treated at the McGill plant.

Geography

Location.—Ely lies in the Robinson mining district, in White Pine County, Nevada (fig. 36). The mines are within the Egan Range, near Steptoe Valley and are connected with Shafter, on the Western Pacific Railroad, and Cobre, on the Southern Pacific Railroad, 140 miles to the north, by the Nevada Northern Railway.

Physical features.—The Egan Range is a typical rugged basin range. Near Ely it is from 6 to 12 miles wide and reaches altitudes of over 8,000 feet The range rises abruptly from Steptoe Valley, its long straight front but slightly broken by embayments. The streams from it debouch through narrow gorges or canyons. At higher levels the gorges broaden out at the expense of softer formations, and the rugged surface apparent from a distance gives way to wide undulating basins of low relief. The Robinson Canyon is such a valley. At Ely (altitude 6,400 feet), where it enters the Steptoe Valley, it is a narrow, steep gorge. Five miles above

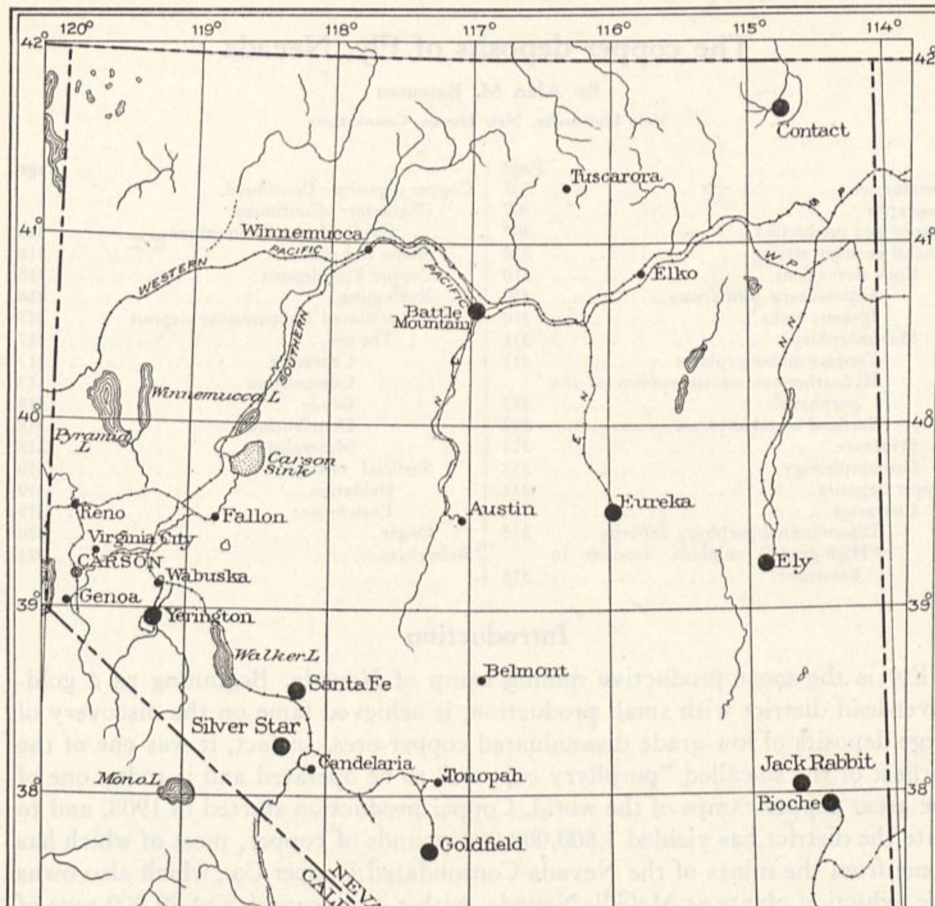

FIGURE 36.—Map of Nevada, showing location of copper-producing districts.

the town it broadens out into a wide interior basin of low relief, excavated from friable rhyolite tuffs or readily decomposed monzonite porphyry. Prominent "flats" are the surface expression of these formations, such as Copper Flat or Weary Flat. It is here that the copper mines are situated, at Ruth, Copper Flat, and Kimberly, at an altitude of about 7,000 feet. Around these basins are irregularly disposed mountains composed of resistant limestone.

The Steptoe Valley is a broad, straight valley floored by debris that slopes gently toward the center. Enormous alluvial cones extend far out into it, and the stream channels, mostly dry, thread their way down these debris piles.

Climate.—The Ely district has low precipitation, few perennial streams, and many intermittent ones. The precipitation varies markedly, being lower in Steptoe Valley and higher in the mountains and at the mines, where winter snows accumulate. The summers are hot and dry; the winters are cold, temperatures below zero being common.

The vegetation is that of the arid Great Basin, with valley floors barren or dotted by sagebrush. The mountains are covered by luxuriant grasses, and forests thrive above 8,000 feet.

History and production

According to Spencer (4, pp. 91–100), mining activity in the Ely district began in 1867. The early mining was confined to gold, silver, and lead, and the production prior to 1908 had an estimated value of about $600,000 (4). At present copper is the predominant metal produced in the district.

The first shipment of copper was made in 1900; the next (29 tons) in 1907. In 1904 the Nevada Consolidated Copper Co. was organized, and by 1905 its properties were estimated to contain 26,000,000 tons of ore (4, p. 96). The Nevada Northern Railway and the reduction plants were then constructed.

The milling of low-grade copper ores was begun in 1908 by the Nevada Consolidated Copper Co.,[1] and this company has remained the great copper producer of the district.

Since 1908 the Ely district has yielded 80,900,000 tons of ore, from which 1,806,000,000 pounds of copper, 754,000 ounces of gold, and 2,546,000 ounces of silver have been recovered. Most of this has come from the properties of the Nevada Consolidated.

In 1929 the two producing mines of the district yielded 6,254,029 tons of concentrating ore, or an average of 17,134 tons a day, from which about 135,000,000 pounds of copper was recovered.

The present reserves of the mines are estimated to be 100,000,000 tons of ore, containing an average of 1.20 percent of copper.

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[1] The Nevada Consolidated Copper Co. was controlled by the Utah Copper Co., which in turn passed into the control of the Kennecott Copper Corporation in 1924; in 1926 the Nevada Consolidated Corporation absorbed outright two other large "porphyry copper" companies, the Ray Consolidated Copper Co., of Ray, Arizona, and the Chino Copper Co., of Santa Rita, New Mexico. The outstanding stock of the Nevada Co. was purchased in 1933 by the Kennecott Copper Corporation, of which the large Ely producer is now a completely owned subsidiary.

General geologic setting

Rock formations

The rocks of the Ely district (pl. 17) consist predominantly of sediments that range in age from Ordovician to Pennsylvanian (4, 8) and have a thickness of around 12,000 feet. The igneous rocks comprise older and younger intrusive monzonite porphyry and late tuffs, rhyolite, and obsidian. The valleys are floored by thick deposits of Quaternary debris. The sediments are folded, faulted, and metamorphosed, and the intrusives are hydrothermally altered. The ore deposits occur in the older monzonite porphyry and in the adjacent invaded rocks and are genetically associated with the intrusions.

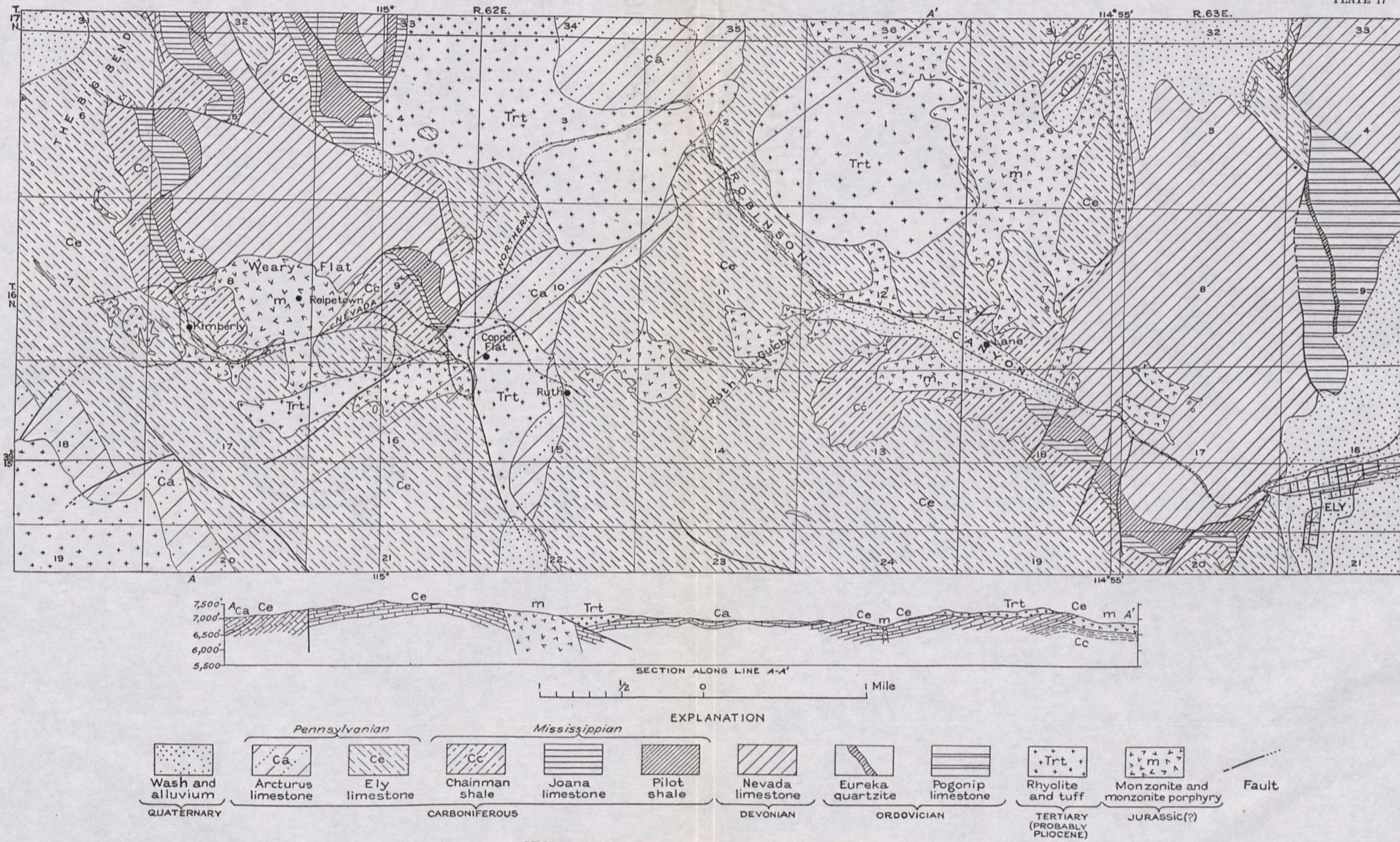
Sedimentary formations.—The formations recognized in the Ely district are as follows (4, 8):

		Feet
Quaternary and Recent	Gravel	1,000+
Pennsylvanian	Arcturus limestone	400+
	Rib Hill formation	3,200
	Ely limestone	1,500–3,000
Mississippian	Chainman shale	425
	Joana limestone	100–400
	Pilot shale	250
Devonian	Nevada limestone	4,000
Ordovician	Eureka quartzite	150
	Pogonip limestone	1,400+

Of these, the Ely and Rib Hill are the most widely distributed (pl. 17). The Ely encloses most of the porphyry intrusions and is the host rock of several of the smaller ore bodies.

Igneous rocks.—The older igneous rocks, considered by Spencer (4) to be of late Jurassic age, are intrusive porphyries, which he ascribes to only one period. I distinguish two, however—an older porphyry (ore porphyry) and a younger monzonite porphyry—and Pennebaker (8) also recognizes two periods, an earlier "ore porphyry" intruded by a later "peanut porphyry." These rocks have a porphyritic texture and the composition of quartz monzonite, although quartz may be lacking. The younger intrusive is in general relatively fresh and consists of orthoclase, andesine, some quartz, hornblende, and brown mica, with apatite, magnetite, and sphene as accessories. The ore porphyry is so greatly altered that its original character is rarely clear. Its texture is clearly porphyritic, and in general it appears to be similar in mineral composition to the younger porphyry. Chemical analyses of the porphyries (without distinction) are given by Spencer (4, pp. 37–39).

Several separate areas of porphyry (pl. 17) are disposed along an east-west zone of folding and faulting about 8 miles long by 1½ miles wide, across the center of the Ely district. Their maximum size is about 1 square mile. The largest ore-porphyry area is about 2 miles long and from 600 to 2,000 feet wide, and in it are the open-pit mine of the Nevada Consolidated Copper Co. and the Morris-Brooks and Emma mines of the Consolidated Copper Mines Co. The main porphyry area of the Ruth mine is 2,200 by 1,200 feet.



GEOLOGIC MAP OF ELY (ROBINSON) DISTRICT, NEVADA

The porphyry bodies are referred to by Spencer (4) as stocks, sills, and dikes. Later mining operations, however, show that some at least of the so-called "stocks"—for example, the Ruth ore porphyry (10)—rest on a sedimentary floor. Similarly Pennebaker (8, p. 165) states that the ore porphyry of the Morris-Brooks mine is a wedge-shaped mass bounded by parallel faults that diverge in dip, and he calls it a "chonolith." The Copper Flat ore porphyry also in part underlies a fault.

The younger porphyry, according to Pennebaker (8, p. 166), mostly flanks the ore zone on the north and occurs in dikes and sills. He considers both porphyries closely related in age. The porphyry in the western part of the region is thought by Pennebaker to have "worked up major fault channelways and 'mushroomed' under moderately flat fault roof structures" (8, p. 165).

The postmineral (probably Pliocene) volcanic rocks (pl. 17) consist of soft bedded white tuffs, with coarse agglomerates at their base, overlain by flows of obsidian and purple and gray rhyolite. They occur mostly as surface flows; some may be intrusive. Their greatest recorded thickness is 468 feet; their original thickness was probably around 800 feet (4).

The volcanic rocks are later than most of the oxidation of the copper ores and most of the faults of the district but in places have been dislocated by post-rhyolite faults.

Metamorphism

The rocks of the Ely district have been profoundly metamorphosed, first by some of the porphyry intrusions, second by the metallizing solutions, and later by surface agencies. The first yielded contact-metamorphic rocks; the second gave rise to penetrating hydrothermal alteration, particularly of the porphyry; the third caused surface silicification, and oxidation and enrichment of the copper ores, with accompanying kaolinization. The last-named processes are considered separately under "Ore deposits."

Contact metamorphism.—The individual porphyry masses of the central zone of intrusions are surrounded by aureoles of metamorphosed limestone and shale.

The shales of the Pilot and Chainman formations have been altered to dense pyritiferous hornstones. Their weathered surfaces yield rusty croppings that have often been mistaken for ore croppings, and considerable sums of money have been needlessly expended upon them.

The limestones, particularly the Ely limestone, have been extensively altered. The changes comprise (*a*) alteration to small bodies of magnetite, pyrite, and associated silicates; (*b*) development of lime-bearing silicate minerals; (*c*) silicification to jasperoid; (*d*) simple recrystallization, yielding gray marble.

The small contact-metamorphic bodies in places carry a little noncommercial chalcopyrite. Garnet, wollastonite, magnetite, and sulphides were detected in the ore.

The metamorphism to lime-silicate rocks is common near the porphyry. In places garnet has been formed on a large scale, but the alteration resulted chiefly in recrystallized limestone with varying amounts of garnet, tremolite, wollastonite, scapolite, epidote, mica, quartz, magnetite, pyrite, chalcopyrite, molybdenite, sphalerite, and a little galena. These rocks also yield rusty outcrops sufficiently resembling the ore croppings to have induced considerable development work upon them.

The jasperoid is the most widespread alteration product of the limestone. Extensive areas of it have been mapped by Spencer (4), and it surrounds most of the porphyry intrusions. The dense grayish to whitish material is a fine-grained quartz or chalcedony that has replaced limestone. Pyrite is commonly disseminated through it, and minute veinlets contain pyrite and chalcopyrite. In places there is a little garnet and tremolite.

The jasperoid may be a lower-temperature phase of the contact metamorphism, but Spencer has shown (4, p. 62) that fluid inclusions in its quartz indicate a hydrothermal formation between 200° and 350° C.; he thinks it has been formed by the same hydrothermal solutions that sericitized the porphyry. However, the jasperoid is widespread, and the sericitization was localized. It is clear that there has been a progressive sequence of events in the igneous activity of the region, starting with the intrusions, continuing with the formation of magnetite-pyrite-lime silicates, and ending with the sericitization of the porphyry and ore deposition. The formation of the jasperoid probably occupies an intermediate position, overlapping somewhat at each end.

Hydrothermal metamorphism of the porphyry.—Most of the porphyry of the central area has undergone some hydrothermal alteration, but where ore occurs the alteration was intense—the intensity being in proportion to the abundance of metallization. This relationship is so striking that the formation of the ore and the sericitic alteration must be due to the same solutions.

All stages of sericitization are represented. Where pyrite is present without copper, partial sericitization has occurred, and where sulphides are absent, sericitization has been slight or lacking. Most of the younger porphyry is free from it. Spencer (4, pp. 57, 58) gives tables showing the actual additions and subtractions of materials that took place during the alteration. However, his comparisons do not distinguish between the older and younger porphyry and therefore may be valueless.

This alteration was apparently more or less contemporaneous with the metallization and took place after the consolidation and fracturing of the outer part of the ore porphyry. The solutions, therefore, must have come from greater depth. Spencer (4, p. 63) believes that the temperature of these solutions was about the same as that of the solutions that yielded the jasperoids.

Surficial metamorphism.—Three varieties of surficial metamorphism (exclusive of ordinary surface weathering) have occurred—one giving rise to ore oxidation and supergene sulphide enrichment (see "Surficial changes"); a second, kaolinization, accompanying the oxidation and sulphide enrichment; and a third, giving rise to "casehardening."

The solutions resulting from ore oxidation partly kaolinized the already sericitized porphyry. This kaolinization was most pronounced where supergene sulphide enrichment was most advanced. It decreased with increasing depth and ceased where the primary sulphides were unenriched. It was clearly a surface phenomenon.

"Casehardening" is a local term for superficial alteration that has given rise to certain knobby, hard croppings, characteristic of the district. Its effects are particularly noticeable along outcrops of fault breccias, whose silicified impervious surfaces are rounded, smooth, and so tough that it is difficult to break off a piece with a heavy hammer. These hardened surfaces range in color from light tan to deep red and resemble chert or jasper. They are composed of rock fragments tightly cemented by silica or iron oxide. At a depth of a few inches to a few feet they pass into soft breccia that can be picked out readily. This process was clearly a relatively recent superficial silicification.

Parts of the ore croppings have been similarly affected, as may be observed particularly well in the caved ground over the Ruth mine.

Structure

The Ely district portrays the dominant tectonic features of northeastern Nevada and the Great Basin. The formations have been warped and faulted along east-west lines, intruded by igneous masses, covered by volcanic extrusives, and then block-faulted and uplifted along north-south lines.

The sedimentary formations were considered by Spencer (4) and Lawson (2, p. 297) to have been broadly folded into a large, though obscure northward-trending syncline. Pennebaker's detailed mapping, however, discloses an east-west anticline (8, p. 164), which is clearest in the eastern part of the district. The axis of this anticline is cut by north-south normal faults that alternately raise and lower blocks of the folded sediments, giving rise to an intricate fault pattern that can be deciphered only by large-scale detailed mapping.

Dominant eastward-trending compression faults in the western part of the district (8, p. 114) have guided intrusion and mineralization. These are cut by much later normal faults, apparently a part of the block-faulting uplift of the range. Pennebaker (8, p. 166) concludes that the major folding of the district preceded the major east-west faulting, which in turn preceded and guided the igneous intrusions. He believes that movement continued along these east-west faults during and after the intrusions, causing the intrusive rocks to be shattered. The largest fault of the region cuts out 5,000 feet of strata (4, p. 46). A prominent normal fault with a northwesterly strike brings rhyolite down against the Copper Flat ore porphyry and forms the eastward termination of the ore. Its throw may be around 500 feet. Another strong north-south fault terminates the porphyry ore in the Ruth mine; it localized a large body of "high-grade" copper ore and played an important part in guiding supergene enrichment solutions.

Geomorphology

Four erosion surfaces are recognizable. The oldest embraces the tops of the Egan Mountains; remnants of a second cap the hills within the Robinson Basin; a third is broadly developed over the Robinson Basin; and a fourth is a recent surface actively encroaching on the third and second. During the erosion that preceded the development of the second surface, porphyry was revealed and ore oxidation probably began. Also, the rhyolite (probably Pliocene) was extruded, because the second surface was developed on it. Block-faulting uplift then occurred. Erosion by the local master stream, Robinson Creek, was renewed. The soft volcanic rocks and the easily eroded porphyry yielded flattish areas, above which projected the limestone and harder jasperoid areas. The third surface was then formed. During this time the porphyry was again uncovered; oxidation and enrichment held sway; and the water table, limiting ore oxidation, was rapidly depressed coincident with erosion.

During the downcutting that led to the present (fourth) surface, the floor of the third was dissected and Robinson Canyon was cut, probably coincidentally with renewed fault-block uplift. The concomitant depression of the water level was probably faster than ore oxidation could keep pace with, resulting in the stranding of secondary sulphides high above the water table.

The debris removed was dumped into Steptoe Valley. The huge alluvial cone opposite Robinson Canyon was formed during a dry period of intermittent stream flow, which Spencer (4, p. 30) correlates with Gilbert's pre-Bonneville epoch (11) and which constitutes the earliest record of Quaternary events in this part of Nevada. Subsequently this alluvial cone became trenched, presumably by perennial streams that must have existed during the flooding epochs of Lake Bonneville (4, p. 31).

Meanwhile, during the development of these land forms, the porphyry ores had been mostly stripped of their volcanic cover; the water table was lowered during the development of the third and fourth surfaces; and more copper ore was subject to oxidation, with the release of copper solutions to bring about supergene sulphide enrichment.

Copper deposits

The principal copper deposits are the low-grade disseminated porphyry ores; minor production comes from smaller "high-grade" deposits of direct shipping ores. The operating mines are the Copper Flat Pit, a large steam-shovel pit, and the Ruth underground mine, both of which belong to the Nevada Consolidated Copper Co.; and the Brooks-Morris and Emma mines, of the Consolidated Coppermines Co.

The Ely porphyry ores have long been considered to owe their commercial grade to supergene chalcocite enrichment. This is not the case. The great bulk of the copper is contained in hypogene chalcopyrite. A relatively thin coating of supergene chalcocite on chalcopyrite or pyrite has added to the copper content of the shallower ores, but most of the deeper ore is entirely hypogene. In this ore chalcocite is mostly lacking or, if present, contributes only a minor proportion of the copper.

The Ely porphyry ores are therefore exceptional and constitute an example of porphyry copper deposits whose commercial grade is not dependent upon sulphide enrichment.

Character

The commercially important copper deposits may be divided into three groups—low-grade disseminated porphyry ores, "high-grade" sulphide deposits in limestone, and oxidized deposits in limestone. The first group yields nearly all the copper of the district.

Disseminated porphyry deposits.—The low-grade disseminated deposits are parts of the porphyry masses that have been impregnated by small grains of sulphides and threaded by minute veinlets of chalcopyrite and pyrite, commonly associated with quartz. Whether a deposit is a commercial body or not is determined by the spacing of the sulphides and the volume of impregnated rock. Most of the commercial deposits are flanked in part and underlain by metallized porphyry that falls below the commercial grade of mining. Thus the shape and size of the deposit will change according to the cost of operations and the price of copper. Material that a few years ago could not be considered ore is today included in the ore reserves. A lowering by 0.2 percent in the grade of ore that can be profitably treated increases greatly the ore tonnage available.

The boundaries of the deposits are thus, in large part, changeable. In part, they are determined by faults or contacts with intrusive rocks, as at the south sides of the Copper Flat Pit and the Ruth mine. In a few places commercial ore extends into the invaded rocks adjacent to the ore porphyry, as in the Pit ore body, but only a minor part of the disseminated ores lie outside of porphyry.

The deposits occupy the crackled upper portions of the ore-porphyry masses. The upper limits of the ore (before oxidation) are the surface of the porphyry, flatly dipping faults, or overlying rocks, but the ore passes into less mineralized porphyry beneath. The bottom of the ore is an irregular surface. As the disseminated deposits lie within the porphyry masses, they are localized by the ore porphyry intrusions, which in turn have been localized by structural weaknesses.

"*High-grade*" *sulphide deposits in limestone.*—Several high-grade sulphide bodies of direct shipping ore occur in the altered limestone near the ore porphyry—for example, the high-grade body of the Ruth mine. This elongated body occupied a north-south shattered zone in jasperoid-lime-silicate-garnet rock, adjacent to the Ruth porphyry contact. In cross section it was shelf-shaped, with an inclined base resting upon the High Grade fault, and the shelf projecting outward into less altered limestone. The body was about 1,000 feet long, as much as 200 feet wide, and 50 feet in height. It contained about 400,000 tons of ore averaging about 7¼ percent of copper. The top was oxidized. The sulphide ore consisted of pyrite, chalcopyrite, sooty chalcocite, and a little magnetite, in a gangue of kaolinized altered limestone. Its high copper content was due to enrichment by which minor chalcopyrite and abundant pyrite had been partly replaced by sooty chalcocite. The ore merged westward from the fault and below into unenriched pyritic rock too lean to mine. The relatively high degree of enrichment was due to the fault, which concentrated the descending enriching solutions upon its upper surface and prevented subfault enrichment. The flange of the shelf probably represents the site of a previous water table below which rapid copper precipitation took place, thus accounting for the richness of the flange and of the base.

Other bodies in the western part of the district are believed by Pennebaker (8, p. 168) to have formed in zones of strong fold distortion, where flat east-west faults are intersected by north-south faults.

Oxidized ores in limestone.—In the western part of the district rich oxidized copper ores consisting of copper oxides, carbonates, and native copper have been mined. The old Alpha mine is an example. Here oxidation is reported to extend to 1,200 feet in depth, with good ore from the 900 to the 1,200 level. The ore body is said to be a replacement deposit in altered limestone and has much associated kaolin (4, p. 126).

Shape and size

As the low-grade disseminated deposits have been developed largely by means of drill holes, their shape and size have been determined from the data yielded by the drilling records. However, many of the central holes bottomed in what was then the lower limit of commercial ore; some of these have since been deepened in ore, thus changing the lower boundaries. Consequently, the lower limits and the ultimate size of the deposits have not yet been determined exactly. The margins of the deposits as a whole have been fairly accurately delimited.

Copper Flat deposit

The Copper Flat deposit, the largest of the three porphyry deposits, has already yielded 57,500,000 tons of ore of 1.40 percent grade. It has been mined by steam shovels, originally from three open cuts, which have now coalesced to form one large pit elongated in an east-west direction.

This part of the deposit is an oval-shaped blanket that thins out on three sides and has a depressed center. It is about 4,000 feet long, from 300 to 2,500 feet wide, and as much as 600 feet thick. Its west side extends an additional 2,500 feet into the Consolidated Coppermines ground.

The deposit was overlain by leached oxidized capping ranging from 20 to 350 feet in depth, much of which has now been removed. The transition between capping and underlying ore is rather abrupt. Immediately below the capping is the workable sulphide ore, with an undulating upper surface. The upper portion of the ore was partly enriched, and the lower portion is mostly primary sulphides. The deposit grades downward irregularly into material below present workable copper content, and an irregular lower boundary is arbitrarily drawn. This boundary, however, may change as new holes are drilled or others are deepened.

Ruth mine

The Ruth is an underground mine in disseminated porphyry ore that lies about half a mile east of the Copper Flat ore body. It has produced to date 13,000,000 tons of ore containing 1.78 percent of copper. It has been opened to the 900 level.

The ore porphyry cuts across the beds and is of irregular shape, being an inclined plug that mushrooms out upward. It is overlain and underlain by altered sediments; its upper surface is bounded in part by the westward-dipping High Grade fault, and its lower surface also dips steeply westward. Its south side dips steeply north, and its north side dips south.

The ore body occurs in the southern half of the intrusive, but all of the porphyry mass is more or less pyritized. The deposit is irregularly oval in plan and is elongated north and south. It lies close to the altered limestone on the south and west and grades into less metallized and less altered porphyry on the north and east. In section the deposit appears as a huge tabular body that inclines 15° W., roughly parallel with the westward plunge of the intrusive. The ore body is about 1,600 feet long, is 1,200 feet in maximum width, and has an average thickness of about 150 feet. The capping overlying the ore ranges in thickness from 110 to 540 feet and averages about 400 feet (5).

Consolidated Coppermines deposit

The deposit worked by the Consolidated Coppermines Co. adjoins the Copper Flat ore body on the west and is really a westward continuation of it in the form of a narrow projection about 2,500 feet long. The porphyry ore is of the same general type as the Copper Flat ore and also occurs in blanket form, though of smaller dimensions than its neighbor.

The ore

Character.—The porphyry ore is a light-gray to cream-colored rock faintly peppered with minute sulphide grains and seamed with paper-thin films of sulphide (mostly pyrite) along joint cracks. Here and there larger veinlets from 1 millimeter to 1 centimeter wide, containing sulphides and a little quartz, traverse the rock in all directions. A glance at the ore from a distance of 3 feet suggests ordinary rock: that it is ore becomes apparent only upon close inspection. The ore as a whole appears massive and has to be blasted or caved. However, it is closely jointed: a large piece under the blow of a hammer shatters to fragments bounded by joint planes, making it difficult to obtain a suitable-sized hand specimen. The ore is brittle and crushes readily. It is relatively light in weight, requiring about 13 cubic feet to make 1 ton.

The sulphide minerals, in general, are uniformly scattered through the rock. A square inch of ore will contain on the average one to two dozen specks of sulphide and about one film veinlet. The individual sulphide grains average between 0.5 and 1.5 millimeters in diameter. The sulphides have formed by replacement of the rock minerals, particularly the feldspars and ferromagnesian minerals.

Composition.—The ore consists essentially of altered porphyry and sulphides. Except for a little quartz, no gangue minerals have been introduced. The older ratio of concentration, approximately 10½ to 1, indicates the quantity of sulphides present—that is, 10½ tons of crude ore yields 1 ton of concentrates (mostly sulphides). The sulphides therefore constitute about 9 to 10 percent of the ore. Probably about one-half of this percentage is pyrite. In the present metallurgical practice the worthless pyrite is rejected, giving a ratio of concentration of about 25 to 1.

A partial analysis of a composite sample of 3,000,000 tons mined from the Copper Flat Pit prior to 1910 is quoted by Spencer (4, p. 110) as follows: SiO_2, 77.35 percent; Al_2O_3, 8.77; Fe, 3.04; CaO, 0.51; Cu, 2.21; S, 3.63. The composition of 1,809,364 tons of ore mined in 1934 was SiO_2, 68.4 percent; Al_2O_3, 9.9; Fe, 5.0; CaO, 0.7; Cu, 1.205; S, 4.0; and of the concentrates, SiO_2, 3.5 percent; Al_2O_3, 2.3; Fe, 27.6; CaO, 0.2; Cu, 29.847; S, 33.9.

The minor metallic constituents are selenium, nickel, silver, gold, palladium, bismuth, and platinum, the quantities of which occur in the order named.

Grade.—The grade of the ore mined to date is as follows:

	Percent of copper
Copper Flat deposit (57,500,000 tons)	1.40
Ruth mine (13,000,000 tons)	1.78
Consolidated Copper Mines Co. (6,600,000 tons)	1.73

The composite grade of the present reserves is 1.20 percent. Within the deposits the grade of the ore varies slightly from place to place. The margins and bottoms are in general leaner than the central portions of the ore. In the earlier mining higher-grade ore was produced than at present, owing partly to the fact that enrichment was greater in the upper part of the sulphide zone but chiefly to the fact that lower-grade material than formerly is now mined as ore.

The high-grade sulphide ores in altered limestone range from 6 to 15 percent of copper.

Distribution.—A noteworthy feature of the Ely porphyry deposits, as well as other porphyry coppers, is the remarkably uniform distribution of ore within the deposits. Minor variations exist, of course, but in the Ely district patches of waste within the deposit are few. This is strikingly illustrated on the 600 level of the Ruth mine, where one can walk for 1,200 feet along a crosscut without encountering waste inclusions or any pronounced variations in grade.

The ore is most abundant in the most shattered portions of the porphyry masses, but there appears to be no definite tendency for these portions to be localized in any particular part of the intrusive. At Copper Flat ore lies against the altered sediments to the south, even extending into them a little at one place, and to the north it fades out into less mineralized porphyry; to the east it extends under the rhyolite cover. At the Ruth mine the ore is localized more on the footwall than on the hanging-wall side of the porphyry.

Mineralogy.—The principal metallic minerals of the porphyry ores are pyrite, chalcopyrite, bornite, chalcocite, and a little covellite. In addition there are small quantities of sphalerite, molybdenite, and magnetite. Gold and silver are contained in the copper minerals. Crystals are uncommon. The chalcocite and covellite are supergene sulphides. They replace chalcopyrite, bornite, and pyrite, with a strong preference for the first two. Under the reflecting microscope the chalcocite is seen to rim the grains of hypogene sulphides and to cut across them along minute fractures.

The paragenesis of the metallic minerals is pyrite, chalcopyrite, chalcopyrite and bornite, bornite, and much later, chalcocite and covellite. Quartz preceded the pyrite.

The gangue minerals are those of the altered porphyry and a small amount of introduced quartz. The capping contains "limonite," chalcedony, jarosite, and locally chrysocolla, copper carbonates, and cuprite; also some soluble copper sulphates, in addition to the kaolinized altered porphyry constituents.

The "high-grade" copper deposits contain the same metallic minerals, but magnetite is more abundant, and among the additional nonmetallic minerals garnet (andradite), epidote, and tremolite occur.

Surficial changes

Weathering has produced pronounced changes in the upper parts of the copper deposits. Oxidation has given rise to a copper-free capping. The iron of sulphide origin has largely remained in the capping; the soluble copper sulphate trickled downward to be deposited below in the form of the secondary sulphides chalcocite and covellite, giving rise to a zone of partial enrichment. In consequence, the deposits are characterized by three zones—an upper oxidized barren zone, an intermediate zone of partial enrichment, and a lower zone of primary sulphides. The last two constitute the commercial ore. The inclusion of the primary zone makes the Ely porphyry deposits different from most other porphyry coppers, whose commercial importance rests upon the conversion of a valueless protore into copper ore through enrichment.

The oxidation and sulphide enrichment began during the pre-rhyolite erosion but ceased while the deposits were covered by the volcanic rocks. The subsequent stripping off of the volcanic rocks again exposed the ore to weathering, and most of the enrichment took place during the later erosion periods, when the water level stood higher than at present.

Oxidation.—The original capping resulted from the oxidation of the primary sulphides, according to the familiar reactions. But with the downward progression of oxidation the secondary sulphide zone repeatedly came under its influence. Consequently, the present capping is largely the aftermath of what had been previously the secondary sulphide zone. It contains hydrated iron oxide, basic iron sulphates, and jarosite; copper has been almost entirely removed; and kaolin is present. Local spots contain minor copper carbonates.

The thickness of leached oxidized zone removed by erosion is unknown; the existing zone is 20 to 540 feet thick, the greatest depth being over the Ruth. The average thickness of the capping over the Ruth is about 400 feet (5) and over the Copper Flat pit about 190 feet. About 1 ton of leached capping has been removed from the pit for each ton of ore extracted.

The porphyry capping from a distance resembles the ore. Heavy iron-stained gossan is absent; the "limonite" content barely arrests the eye. Closer inspection shows the capping to be of a brownish cream-color, with "limonite" confined to seam faces and not permeating the whole rock. Minute cavities occupied by box-work "limonite" mark the former site of sulphides, and the character of the box work indicates the nature of the former sulphides. The "limonite" of sulphide derivation has mostly remained fixed in these cavities; transported "limonite" is largely lacking. The character of the alteration, the lack of pervasive "limonite" stain, and the nature of the cavity fillings give evidence of derivation of the capping from an enriched copper ore.

The bottom of the oxidized zone is on the whole a flattish surface, with local irregularities consisting of sags of oxidized capping extending down several tens of feet into the underlying sulphide ore. This irregularity is probably to be explained by local permeability and by late submergence of the water table.

Enrichment.—The copper sulphate solutions formed during oxidation attacked the bornite, chalcopyrite, and pyrite of the primary ore and replaced them in part by chalcocite and covellite to form a zone of partial sulphide enrichment. The enrichment was highly selective: the sparse grains of bornite have been largely replaced, the chalcopyrite partly, and the pyrite only slightly. The seam pyrite has hardly been affected, and discrete grains have been replaced in preference to veinlets.

The degree of enrichment at Ely is much less than in most other porphyry deposits. In general the coating and veining of the yellow sulphides by chalcocite is relatively thin. In the disseminated ore reserves as a whole the added content of copper due to supergene sulphides is relatively small; the ore would still be of good minable grade even if no enrichment had occurred. Most of the deeper Pit ore has had little or no enrichment, although in the upper part more complete enrichment occurred. The distribution of enrichment was irregular. Patches of unenriched ore in the Pit lie close to well-enriched ore at the same altitude; the south side of the Pit is more enriched than the north side; the ore beneath rhyolite on the east side is mostly unenriched. This erratic distribution is probably due to the control of enrichment by shattered areas, affording more complete enrichment; by impervious faults, causing good enrichment on their hanging-wall sides and poor below; by the presence or absence of rhyolite cover; and by the position of the ore with respect to past erosion surfaces.

The high-grade ore bodies have undergone more thorough enrichment, and their high copper content is due almost entirely to this process.

Origin

The copper metallization was one event in the pre-rhyolite igneous activity of the region. Its close relation to the porphyry makes the conclusion inescapable that the ore and the porphyry emanated from the same source. The contact metamorphism, the formation of the jasperoid, and the sericitization were likewise associated with the porphyry intrusions, so that all had a common origin and represented successive stages in the igneous activity. The copper minerals were formed largely by replacement of the porphyry by means of hydrothermal solutions. The sericitization was also the result of the action of hydrothermal solutions, and Spencer (4) has shown that the jasperoid was formed by means of hot water solutions. The jasperoid is associated with all the porphyry intrusives, regardless of whether they are sericitized or contain ore. The sericitization, however, did not occur with all the porphyry but was mostly confined to the places of copper metallization. Therefore, the jasperoid formation was distinctly a feature of the porphyry intrusions, and the sericitization and copper metallization were localized phenomena.

The contact metamorphism was probably an early phase of thermal activity accompanying igneous intrusion; the formation of the jasperoid a later phase; and the sericitization and copper metallization a still later phase. Probably all phases were parts of a continuous process and overlapped to a certain extent. The source of the hydrothermal solutions is to be sought, not in the ore porphyry itself, but in the same magmatic reservoir from whence sprang the two porphyry intrusions. Thus the copper deposits are of igneous origin and represent a hydrothermal phase of the igneous activity that gave rise to the porphyry intrusions and their accompanying phenomena.

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The copper deposits of Yerington, Nevada

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The Yerington district is in Lyon County, western Nevada, 50 miles southeast of Reno. (See fig. 36.) In the early days of mining on the Comstock lode it supplied bluestone from its oxidized outcrops for the silver mills, but before 1912 there was no great output of copper. Since then, to the end of 1930, it has produced about 110,000,000 pounds of copper.

The rocks of the district fall naturally into two sharply contrasted groups, separated by a great unconformity—an older, Mesozoic group, to which the copper deposits are restricted, and a younger group of Tertiary rocks, chiefly lavas and tuffs. The oldest rocks, of Triassic age, comprise andesites, keratophyres, and limestone, with subordinate quartzite, shale, and gypsum. They are at least 8,000 feet in total thickness, of which the volcanic portion comprises 3,200 feet. They were intruded, at or near the end of Jurassic time, by a medium-grained basic granodiorite, which was followed in larger volume by quartz monzonite. These intrusions intensely metamorphosed the andesites and keratophyres and converted much of the limestone into wollastonite and other calcium hornfelses, among which aphanitic grossularite garnetites predominate. About one-half of the Triassic area consists of such calcium silicate rocks. After this metamorphism an immense number of quartz monzonite porphyry dikes were injected into the granodiorite, the quartz monzonite, and the adjacent garnetites. Faulting then ensued, breaking and displacing the dikes, and along some of the faults metalliferous solutions rose and formed the copper deposits.

The main ore bodies consist of chalcopyrite and pyrite in a gangue of pyroxene, andradite, or epidote. They are thus of the contact-metamorphic type, but magnetite and hematite are conspicuously absent. The ore, essentially unenriched by supergene sulphides, averaged, prior to 1920, from 2.75 to 6 percent of copper, with gold and silver present in traces only. Later, ore carrying less than 2 percent was worked, and in 1928 the Bluestone mine operated on ore carrying as little as 1.13 percent of copper.

The ore bodies were formed by the replacement of comparatively pure limestones. Andradite and a pyroxene intermediate between diopside and hedenbergite, which forms radial aggregates as much as 10 inches in diameter, are the principal silicates. Most of the ore bodies are small fractions of the associated garnet-pyroxene masses. As much as 200 feet of barren andradite rock in places underlies the ore. In general the ore tends to occur between the garnet-pyroxene rock and the limestone: it lies on the "limestone side" of the contact zone. The greatest distance at which an andradite mass occurs from the exposed contact of plutonic rock is 2,500 feet.

Specially notable features are breccias of grossularite garnetite that are cemented by high-iron andradite and sporadic chalcopyrite, thus clearly showing the distinctness of the two periods of garnetization. The ore of one of the principal mines (the Bluestone) is a breccia composed of angular fragments of garnetite, of quartz-pyroxene hornfels, and of quartz monzonite porphyry intrusive into the garnetite, all the fragments cemented and partly replaced by chalcopyrite, epidote, quartz, and pyroxene.

Although in places the pyroxene has been altered to actinolite, this alteration appears not to have been connected with the introduction of the sulphides, for sulphides are not uncommonly embedded in pyroxene that shows no trace of alteration to actinolite. Broadly considered, the sulphides and associated silicates were formed essentially at the same time. However, the tendency of the ore to occur on the "limestone side" of the silicate masses suggests that in these deposits the maximum deposition of the sulphides occurred later than the maximum deposition of the silicates.

An enigmatic feature in the geology of the ore deposits is that, although large veins of coarse marialitic scapolite occur in the quartz monzonite, no traces of scapolite were detected in the pyrometasomatic deposits, and therefore in the Yerington district, as in so many other districts of pyrometasomatic deposits, the problem remains open as to whether chlorine was or was not the agent that facilitated the migration of the copper, iron, and other elements from the magma into the contact zone.

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Minor copper-producing districts in Nevada[1]

By T. B. Nolan

United States Geological Survey, Washington

The following Nevada mining districts, in addition to Ely and Yerington, have each produced more than 1,000,000 pounds of copper since 1902: Jack Rabbit and Pioche districts, Lincoln County, 15,900,000 pounds (1); Battle Mountain district, Lander County, 14,200,000 pounds (2, pp. 157–171); Santa Fe district, Mineral County, 8,900,000 pounds (3; 4, pp. 153–154); Goldfield district, Esmeralda County, 7,600,000 pounds (5, 6); Yellow Pine district, Clark County, 3,300,000 pounds (7); Eureka district, Eureka County, 1,900,000 pounds (8, 9); Contact district, Elko County, 1,700,000 pounds (4, pp. 40–41; 10); and Silver Star district, Mineral County, 1,100,000 pounds (2, pp. 171–181; 4, pp. 154–155).

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Santa Rita and Tyrone, New Mexico[1]

By Sidney Paige

Ministry of Mines, Ankara, Turkey

Regional geography

Santa Rita and Tyrone are in Grant County, southwestern New Mexico—Santa Rita 12 miles east and Tyrone 10 miles southwest of Silver City. As shown on plate 18, Silver City is connected by a branch line of the Atchison, Topeka & Santa Fe Railway with Deming, New Mexico, and shorter spurs of this railway serve Santa Rita and Tyrone. The Southern Pacific Railroad passes through Deming.

Southwestern New Mexico and southeastern Arizona embrace a region in which several geomorphic divisions merge without definite boundaries. The Rocky Mountain province, as shown in figure 15, is succeeded to the south by the Mexican Highland division of the Basin and Range province. The Colorado Plateaus stand as a buttress between the Basin Ranges on the west, trending in general northwest, and the Rocky Mountains on the east, trending north. The Silver City region lies south of the plateaus, where the ranges of the Mexican Highland diverge to form these two mountain systems. On the northwest rise the Mogollon, San Francisco, and Tularosa Ranges to altitudes of 10,000 feet. To the south, a semiarid desert broken only by scattered islandlike eminences stretches for many miles. Thus while the region includes mountains, foothills, and desert plains, all but the northern part is characterized by short northwestward-trending ridges separated by waste-filled valleys, the dominant topographic forms of which reflect processes of erosion operative in a semiarid region.

The rainfall is insufficient to produce perennial streams; the streams rise to floods during torrential downpours but sink to trickling rivulets as clouds disperse. As this intermittent but violent stream action is one result of a prevailing climatic condition that tends to produce rapid rock disintegration and very effectual removal of waste material from higher lands, most of the streams, although degrading in their upper courses, are overloaded and aggrading in their lower reaches, so that many mountain masses appear partly engulfed by surrounding accumulations of gravel and sand.

Regional geology

Inasmuch as the copper deposits of Tyrone and Santa Rita, genetically considered, have much in common, a sketch of the regional geology will precede the descriptions of the two mining districts.

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During the Tertiary period andesitic, basaltic, and rhyolitic lavas, tuff, sand, and gravel were spread over the Silver City region; later these sheetlike accumulations were invaded by many subcircular stocks similar in composition to the lavas, and widespread normal faulting followed.

The faults are systematically alined: a major system trends northwest, and a secondary system northeast. These faults so disturbed the lava beds that differential erosion through a long period stripped the volcanic covering from large areas, thus revealing a substantial section of Paleozoic and Cretaceous strata. (See pls. 18 and 19.) That faulting has continued intermittently down to Quaternary, perhaps Recent time is firmly established by the widespread and extended fault lines that displace Quaternary gravel.

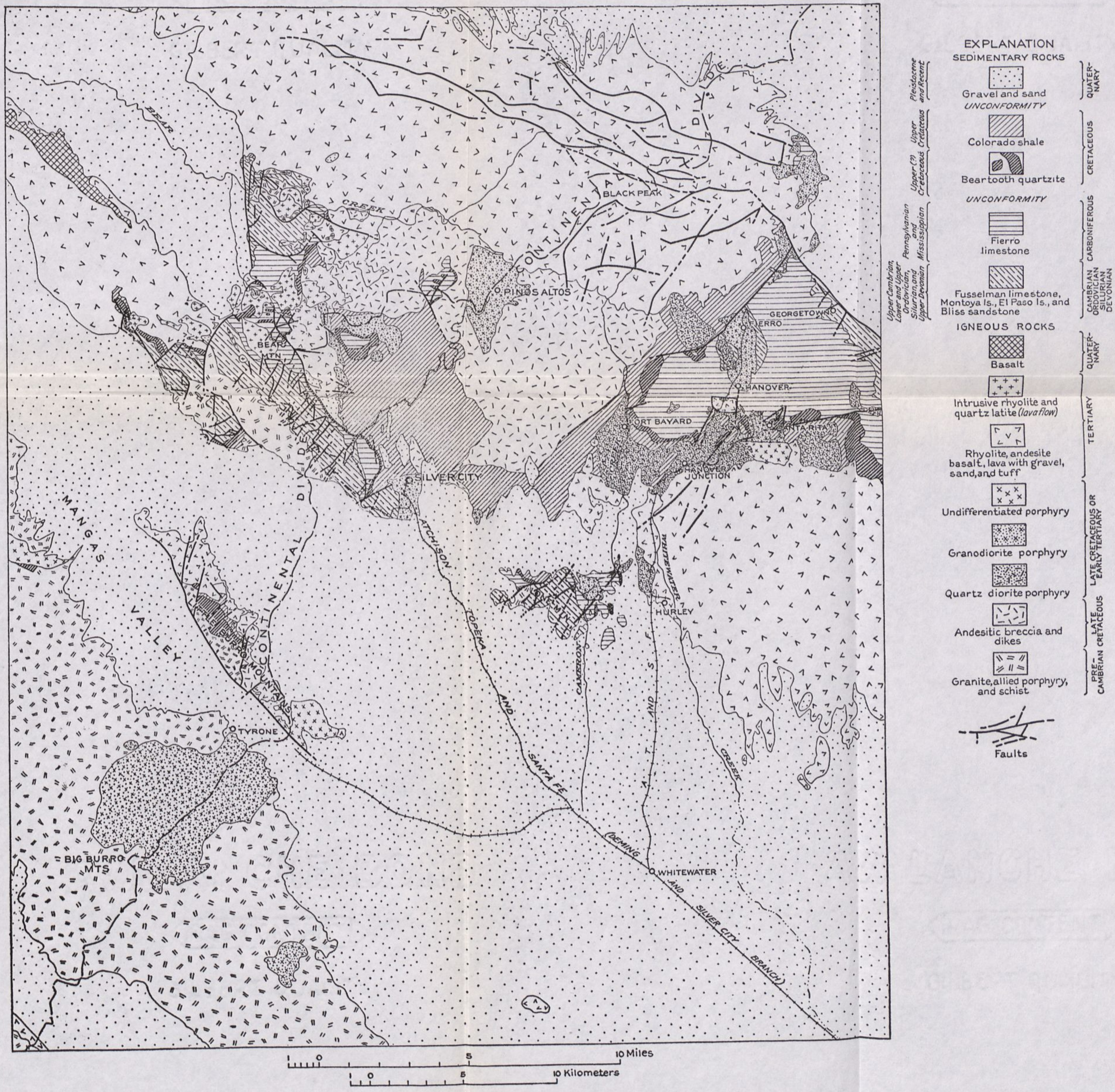
The erosion succeeding this normal faulting has cut so deeply into the underlying rocks that over large areas the pre-Cambrian basement of igneous and fragmentary schistose terranes is revealed. The Paleozoic rocks rest upon a gently undulating or nearly flat surface carved on this ancient basement. They include sandstones, limestones, and dolomites, ranging in age from Upper Cambrian to Permian, in the aggregate about 2,700 feet thick. No great structural disturbances affected these beds before the deposition of Cretaceous sediments upon them, but substantial warping or tilting must have occurred during Triassic and Jurassic time, for the unconformity beneath the basal Lower (?) Cretaceous quartzite (the Beartooth quartzite) is widespread and profound. This quartzite rests on Permian limestone near Santa Rita, but west of Silver City it rests on pre-Cambrian rocks.

Three periods of igneous activity followed the deposition of the Cretaceous strata, but all preceded the violent outpourings of Tertiary lava to which reference has already been made. The record of the first of these periods is somewhat obscure, but apparently it involved both extrusion of basic breccias during Cretaceous sedimentation and intrusion of countless andesitic and basaltic dikes into the Cretaceous Colorado shale, for over many square miles these igneous rocks break the continuity of the sediments. This volcanic period has been correlated with that in western Graham County, Arizona (2, pp. 25–28), and is regarded as Upper Cretaceous.

The igneous intrusions of the second and third periods cannot be so precisely dated. They are both regarded as late Cretaceous (?) but may be early Tertiary.

During the second igneous period laccoliths, sills, and cross-breaking masses of quartz diorite porphyry were intruded, particularly in the area between Fort Bayard, Santa Rita, and Georgetown but also farther west. The lowermost sills, within the Paleozoic strata, are thin sheets; the uppermost, within the Cretaceous strata, are from 500 to 800 feet thick. The lower sills sought out weak strata—the Devonian Percha shale or shaly members of the Pennsylvanian; the thick sills or laccoliths invaded the Colorado shale at various horizons within a few hundred feet above the Beartooth quartzite. The shapes of these masses imply some doming of the beds above them.

During the last pre-lava invasion large masses of granodiorite or quartz monzonite porphyry were violently injected. The contemporaneous intense folding of the invaded rocks was certainly in part related to the violence of the injections.



GEOLOGIC MAP OF SILVER CITY QUADRANGLE, NEW MEXICO

Generalized from U. S. Geol. Survey Geol. Atlas, Silver City folio (no. 199), 1916. The geology of the Santa Rita quadrangle, a part of this area, is shown in greater detail on plate 19, which is based on later mapping and differs in some respects from this map.

The granodiorite stocks at Tyrone, Hanover, Fierro, and Santa Rita, which break through quartz diorite porphyry and Paleozoic and Cretaceous sediments, belong to this period. These granodiorite intrusions at Tyrone and Santa Rita carry much of the copper ore. A long period of erosion probably succeeded the injection of the granodiorite stocks, and after this period the Tertiary lavas spread far and wide over a very irregular surface. The post-lava faulting is referred to above.

A widespread and significant geomorphic feature was developed during the Quaternary erosion cycle. Hand in hand with the alluviation of intermontane valleys went on a related process of down-cutting and the formation, along mountain borders and some mountain masses, of remarkable planated rock-cut surfaces. These surfaces, toward the mountains, are either thinly veneered with gravel or bare; toward the valleys they normally dip beneath the gravel sheet. The surfaces have been described in detail elsewhere (3, 1, 4). Their origin may be briefly epitomized in the following conclusions (3, p. 450):

(*a*) Erosion within an enclosed-basin system in an arid climate tends ultimately to produce surfaces of very low relief about the borders of the gravel sheet which accumulates within the basin. (*b*) The gradual rising of the gravel filling implies an equally gradual rising of the local baselevel. (*c*) The surface resulting from such a shifting system tends ultimately to take the form of a sloping planated surface, most perfect at its mountainward side and progressively more irregular valleyward beneath the gravel cover. (*d*) Interstream erosion, lateral cutting at edges of accumulating fans, and progressive burial of low-lying areas govern the formation of the rock-cut surface. (*e*) The abnormally steep mountain flank against which the rock-cut plain abuts is considered the normal product of the three processes mentioned above. (*f*) Sheet-flood erosion is considered a result of the rock-cut plains and not a cause of the plains, as thought by W J McGee. (*g*) The old planated surfaces near Silver City, though now dissected because of readjustments of drainage due to faulting, are regarded as examples of the type described in the Sonoran district.

The prolonged erosion indicated by these surfaces was effective in the enrichment of the copper ores at Tyrone and Santa Rita.

Santa Rita (Chino) deposits

History

The Central mining district, sometimes called the Hanover district, which includes Santa Rita, appears to have been organized about 1860, but the copper at Santa Rita had then been known for many years. It is stated that about 1800 the croppings near which the Romero shaft was afterward opened were shown to a Spanish officer, Lieutenant Colonel Corrasco, by a friendly Apache chief. Later a concession was granted to Don Manuel Elguea, of Chihuahua, Mexico, a subdelegate of the Spanish court, who contracted to furnish the Viceroyalty of New Spain with copper for coinage. In 1804 Elguea purchased this property and began production. After his death, in 1809, rough metallurgical works are said to have been provided and the metal transported by pack train under military convoy to Chihuahua and thence to Mexico City. A triangular adobe fort with massive towers at the corners was erected as a protection against the hostile Apaches. Two of the towers were standing as late as 1909, and one has been preserved as an interesting historical monument.

About 1822 the property was leased by the widow of Elguea, and from 1826 to 1834 it was worked by Robert McKnight. Later it was operated by one Sequerros, in the decade 1850–60. From 1860 to 1870 the property was held by Sweet & Coste and appears to have been worked except for a period following 1862, when the territory was invaded by Confederate forces under General Sibley, the works destroyed, and much copper confiscated.

After the Civil War efforts were made by different persons to obtain title to the Santa Rita mines under the mining laws of the United States. All applications for patent were denied, however, with the ruling that the claimants had no right to the mines, which had been known for more than half a century as belonging to the Elguea estate.

In 1873 M. B. Hayes and associates obtained quitclaim title from the heirs of Elguea and confirmed their ownership by patents from the United States Government.

About 1881 the Santa Rita mines were purchased by J. Parker Whitney, and in 1882 the plant included a stamp mill with jigs, a water-jacketed blast furnace, and a reverberatory refining furnace. Under the ownership of Mr. Whitney the property was worked mainly by tributers. In 1897 a lease and bond was given to the Hearst estate, and development work resulted in the discovery of a large deposit of sulphide ore in the southwestern part of Santa Rita Basin. In 1899 the property was sold to the Santa Rita Mining Co. Leasing was continued, and ore carrying about 10 percent of copper was purchased from lessees by the company. Material from old dumps was treated in a 90-ton concentrator, and an experimental leaching plant was installed.

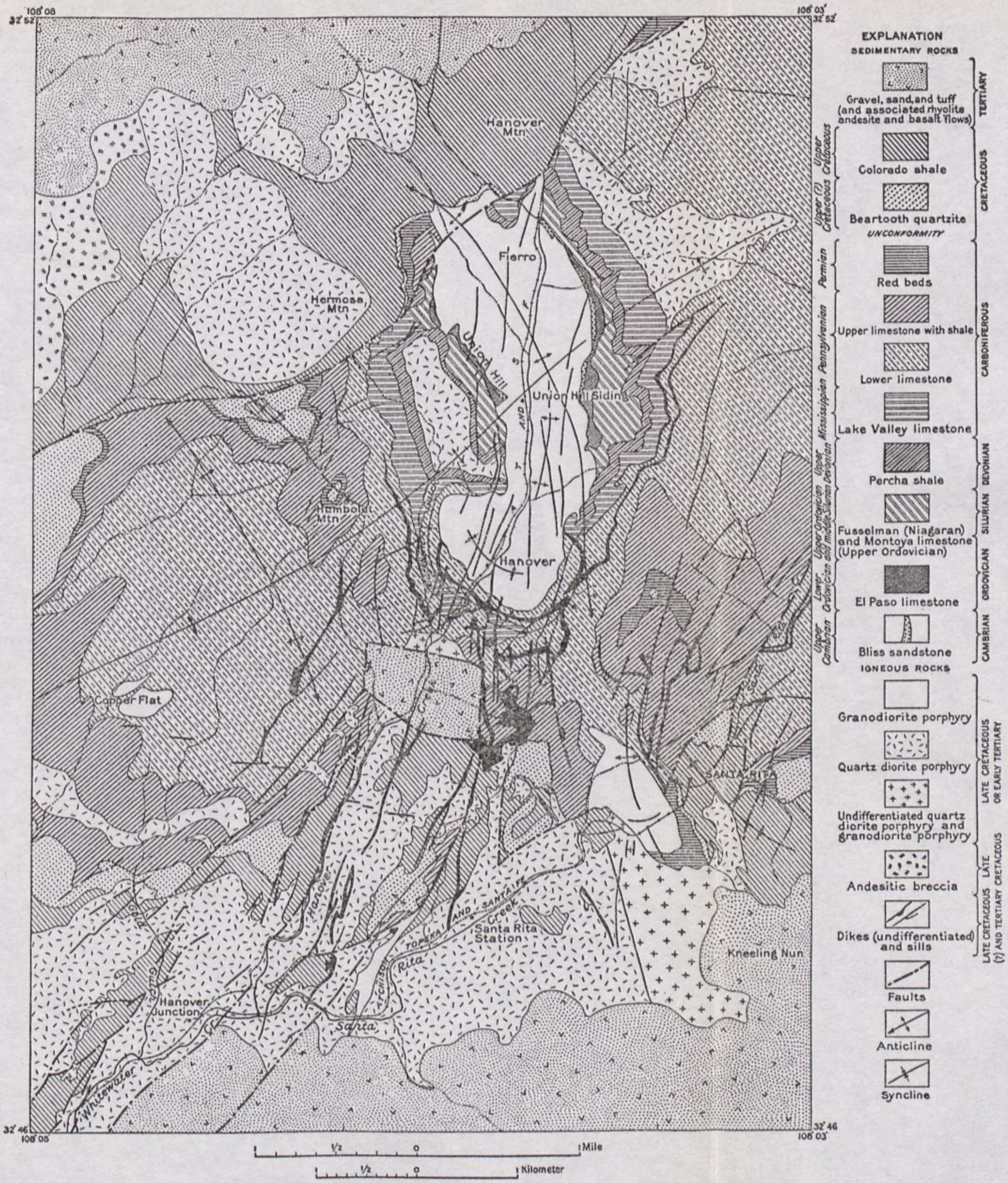
Exploration work carried on about 1906 by the Santa Rita Mining Co. was unsuccessful, and in 1909 the property was sold to the Chino Copper Co., the present owner. This company was absorbed in 1926 by the Nevada Consolidated Copper Co.

Geology

The copper ores at Santa Rita, as well as the zinc and iron ores of Hanover and Fierro, a short distance to the north, were formed by mineralization that may have accompanied but mainly followed the emplacement of the granodiorite stocks. These masses and the invaded rocks around them were intensely fractured, perhaps by the final upward movements of the cooling solid intrusives. The ore deposits are due chiefly to the widespread hydrothermal alteration that immediately followed as an end-effect of the intrusions.

Dikes of granodiorite porphyry invaded the stocks and surrounding rocks about this time. Mineralization preceded and also followed the intrusion of these dikes. Thus fracturing, hydrothermal metamorphism, ore deposition, and the intrusion of the dikes may all be regarded as elements of an episode of monzonitic invasion.

At Santa Rita the granodiorite porphyry stock invades Paleozoic and Mesozoic sediments and a mass of quartz diorite porphyry. (See pl. 19.) The southern boundary of the granodiorite where it cuts the quartz diorite porphyry is obscure, for widespread hydrothermal metamorphism has rendered indistinguishable the invading and invaded rocks, both igneous and sedimentary. The granodiorite, where unaltered, is similar petrographically to the larger mass at Hanover.



GEOLOGIC MAP OF SANTA RITA QUADRANGLE, NEW MEXICO

Geology by A. C. Spencer.

The silication of limestone between Santa Rita and Hanover suggests that the two stocks are connected at moderate depth.

The earlier quartz diorite porphyry is probably part of the Fort Bayard laccolith. South of Santa Rita this rock breaks across Permian red beds, the Beartooth quartzite, and the Colorado shale, suggesting that here or somewhat farther south, beneath the Tertiary lavas, may be the area where the magma arose through the basement rocks. Churn-drill records show a thickness of at least 945 feet.

The granodiorite deformed the invaded sedimentary rocks so that they dip away from the intrusive. At the northeast side this dip is very local, for the regional dip of the Pennsylvanian formations is southward, toward the stock. The axis of the anticline indicated by these dips trends northwest. A short distance to the east a synclinal depression trends in the same direction. These and comparable folds farther west may be due to the intrusion of the magma.

After the emplacement of the granodiorite, and owing perhaps to waning upward movements of intrusion, the borders of the rigid mass, as well as the adjoining wall rocks, were intensely fractured. Thorough hydrothermal metamorphism, with sulphide mineralization and dike intrusion, ensued. Where sulphides are abundant there has been intense fracturing, but where fracturing was relatively slight the mineralization has also been slight. The ringlike arrangement of the ore bodies at Santa Rita strikingly illustrates this relationship, for the core of relatively unfractured granodiorite is relatively unmineralized. (See pl. 19.)

Copper deposits

Much ore was formed in the sedimentary rocks adjoining the granodiorite mass, particularly on the east side of the stock, where Permian limestone, Beartooth quartzite, and Colorado shale contained ore, and at the south end, where Permian limestone and diorite contained ore. Considerable Colorado shale was mined on the southwest side of the stock, and the smaller ore bodies along the northwestern border lie next to the contact. These facts warrant the conclusion that mineralizing solutions discovered those places where fracturing was highly developed—namely, the borders of the intrusion—irrespective of the host rock.

The overburden above the ore bodies is extremely variable in thickness. There is none over the northwestern and northeastern portions of the ore and small areas in other sections, but about 150 feet over the southern portion. The top and bottom of the ore are very irregular. In the main part the ore is 600 feet thick, but it diminishes to 300 feet or less along the margins. None of the ore bodies have been delimited by drilling either vertically or horizontally (6, p. 6).

The value of the ore at Santa Rita is due directly and almost entirely to enrichment. Primary mineralization by pyrite and chalcopyrite accompanied the thorough silicification and sericitization of the fractured rocks. Thus Colorado shale was altered to a porcelaneous siliceous rock, distinguishable from altered porphyry only by painstaking examination, and quartz diorite porphyry in its altered facies is distinguished with difficulty from altered granodiorite.

The minerals of the deposits are chalcocite, pyrite, malachite, azurite, chrysocolla, cuprite, and native copper. The chalcocite and chalcocite-coated pyrite, which are the most abundant, are generally disseminated through the rocks and also fill countless seams and stringers. Quartz, sericite, halloysite, and kaolin are common gangue minerals.

Regional studies have shown that enrichment was interrupted by eruptions of lava but resumed after the erosion of the lavas in Quaternary time. The horstlike uplift of the area north of Santa Rita led to the erosion of the lavas from the Hanover and Santa Rita intrusive stocks. Several faults east of Santa Rita probably played a part in this uplift. One, the Romero fault, approaches the stock from the northeast. Several faults west of Santa Rita also played a part in the uplift.

Tyrone deposits

History

Until about 1880 the Burro Mountains were the stronghold of the savage Apaches, and it was a common belief that no prospector who wandered into the region ever returned. Probably the Indians mined for turquoise before the district was known to white men.

Although John E. Coleman, "Turquoise John," is generally credited with being the discoverer of the Tyrone district, having made locations of both copper and turquoise in 1879, it seems that Robert and John Metcalf made locations as early as 1871. The St. Louis deposit was discovered in 1879 by James Bullard, John Swisshelm, and J. W. Fleming, and shipments of surface ore were made to Denver. The Val Verde Copper Co. was organized, erected a 50-ton reverberatory furnace, and shipped matte 50 miles by wagon to Deming, the nearest railroad point. The ore was obtained mostly from the St. Louis mine. The company soon failed.

About 1881 Judge Deming organized the Alessandro Copper Co. to work a group of claims 3 miles east of the St. Louis mine. The low grade of the ore, the lack of a railroad, and the attempt to leach the ore resulted in failure. Meanwhile the Sampson deposit was discovered by George Sublett and Robert Thompson.

In 1904 Theodore Carter interested the Leopold Brothers, of Chicago, in the St. Louis mine and other properties and organized the Burro Mountain Copper Co., which took over the St. Louis, Sampson, Boston, and other claims. A 150- to 300-ton mill was built at Leopold and treated 4 percent ore from the Sampson and St. Louis claims. Later in 1904 Phelps, Dodge & Co. bought a third interest in the company and acquired an option on the remaining two-thirds of the property.

About 1905 the Comanche Mining & Smelting Co. and the Copper Gulf Development Co. started work in the camp. They merged later as the Savannah Copper Co.

In 1906 the Briggs Oliver Development Co. took under option the Burro Chief group and started three shafts at Tyrone. This company later became the Tyrone Development Co. and still later the Chemung Copper Co. It carried on extensive development work. The Phelps Dodge Co. bought out the Leopold interests in the Burro Mountain Copper Co. and in 1913 purchased the Chemung Copper Co. and several individual claims.

Geology

Rocks.—A summary statement of the regional geology is given on preceding pages. Plate 18 shows the broad features of geology and structure.

All the bedrocks exposed in the Tyrone district are igneous intrusives. Semi-consolidated gravel covers several square miles, but drilling through these superficial deposits has revealed no older sediments.

Cretaceous (?) granodiorite (quartz monzonite and quartz monzonite porphyry) forms the largest single rock unit, a roughly circular stock invading pre-Cambrian granite. It covers about 15 square miles in the center of the district.

Dikes and small masses of quartz monzonite porphyry occur both as offshoots from this main mass and as later dikes cutting through it. Tertiary rhyolite dikes are present but not abundant in this area.

Structure.—As all the rocks of the Tyrone district, except the gravel, are intrusive, their structural relations have to do wholly with intrusion, faulting, and fracturing. Folding plays no evident part in their interrelations.

Faulting has been extensive in the region about Tyrone. Of the larger northwestward-trending breaks (see pl. 18) one that forms the western scarp of the Little Burro Mountains crosses the Tyrone district. This fault tilts the pre-Cambrian rocks of the Little Burro Mountains and the overlying Cretaceous sediments toward the east, and probably the relatively downthrown rocks west of the fault are also tilted eastward. Two of the northeastward-trending faults, if continuous southwestward across the Mangas Valley, must enter the Tyrone district just west of Tyrone, and field evidence suggests that they do.

Within the Silver City region as a whole and at Santa Rita and Tyrone in particular, faulting and fracturing, in late Cretaceous or early Tertiary time, preceded the extravasation of the widespread floods of Tertiary lava, thus preparing the ground for much of the primary mineralization and metamorphism in these districts. After the lavas had been poured out, faulting again proceeded on a grand scale, as shown by the numerous faults within the lavas. This later faulting accelerated the enrichment of the copper ores.

Fracturing.—Fracturing of the rocks in the Tyrone district has locally been intense and has been accompanied by extreme hydrothermal metamorphism.

The principal fracture zone of the district is included within a roughly triangular area whose base may be considered the gravel and bedrock boundary between Tyrone and Oak Grove and whose apex is about 2 miles southwest of Leopold. Fracturing is most intense along the northwest side of this triangle, dying out gradually to the southeast. The fracture zone is independent of rock type, involving both granite and quartz monzonite porphyry. Beyond the limits of the principal zone intense fracturing is confined to individual veins and shear zones.

The fractures may be regarded as distributive faults in which the movement is taken up by many small breaks. The individual fractures are strikingly discontinuous. Extending for a few feet or for several hundred feet, one dies out and its place is taken by another having a more or less different attitude and displacement. Even the fractures showing considerable movement are thus compound.

The fractures, both the minute hairlike breaks and those that carry brecciated zones 8 or 10 feet wide, are characteristically uneven and warped, both vertically and horizontally. Although a particular zone of movement may have a well-defined trend, the individual fractures composing it follow this direction only approximately. The fractures trend generally within the northeast quadrant, and the prevailing dip is east, generally at rather high angles, though there are many exceptions in both strike and dip.

At two places there are rather unusual brecciated zones in which the broken ground appears independent of any definite set of fractures. Probably faulting and intrusion caused these breccias. During the invasion of the quartz monzonite porphyry the pre-Cambrian granite was subjected to tensional stresses, rugged gaps were torn in it, and the magma flowed in to fill these openings. Repeated movements similarly disrupted the invading rock. Some of this movement was compensated by normal faulting. Elsewhere extensive blocks of ground apparently collapsed as the magma advanced. A similar explanation is offered for the Breccia ore body. In brief, the breccias probably represent intrusion phenomena connected with late stages of the invasion.

The rocks throughout the several fractured terranes have, to varying degrees, been altered and replaced by sericite, quartz, and pyrite, with lesser amounts of chlorite, biotite, and chalcopyrite. Superimposed upon this primary alteration supergene concentrations of copper minerals have been brought about. In consequence outcrops within the more intensely fractured areas are iron-stained and siliceous and in places constitute typical gossans.

The fracturing was a necessary forerunner of the alteration, for the unfractured rocks show no appreciable alteration, and the intensity of alteration is independent of the rock type affected and a direct function of the intensity of fracturing.

The primary alteration was produced by ascending hot alkaline solutions, rising presumably from the lower portions of the invading quartz monzonite porphyry; the secondary alteration was produced by descending cold, slightly acidified rain waters, active principally above the ground-water table. The ore deposits of the district are due to both processes but particularly to the second, which was essential to the enrichment of the copper-bearing pyrite and chalcopyrite.

Copper deposits

The principal copper deposits of the Tyrone district are chalcocite ore bodies in porphyry and granite. No primary ore is mined in the district. The deposits exhibit all the characteristics of the now well-recognized chalcocite "porphyry" ore. The chalcocite is either disseminated regularly throughout large masses of fractured country rock or concentrated along exceptionally strong veins or shear zones. The valuable ore bodies are characterized by both these features. The ores are everywhere overlain by ground of variable thickness, either barren of copper minerals or containing carbonates and other oxidized copper minerals, and at varying depths beneath the workable chalcocite ores the primary sulphides are everywhere encountered. The deposits are not the result of enrichment alone but clearly reveal the effects of perhaps equally extensive impoverishment.

The principal ore bodies lie within a northeastward-trending zone of fracture between Leopold and Tyrone. They are very irregular in size and shape, ranging from roughly blanketlike masses, grading upward into oxidized ground and downward into primary pyrite masses, to strong veins or shear zones which are likewise barren near the surface and too lean to be of value below, where chalcocite gives way to primary pyrite.

The East ore body, about 700 feet long and 600 feet in greatest width, related to two strong fractures, is typical of the blanket type. At top and bottom the body has little horizontal extent, but it swells notably at the middle, the form being controlled somewhat sharply on the west and northwest by the St. Louis and North veins respectively. To the east and south the ore merges into the country rock.

The so-called "flat veins" of the Chemung group are typical of the shear-zone type. Here strong central anastomosing veins constitute, with the wall rock, profitable ore bodies. The richer bodies near Leopold are roughly cigar-shaped.

Probably all these ore bodies were localized by the presence of an appreciably greater than average amount of primary chalcopyrite.

Two major groups of developed ore bodies may be recognized. One of these comprises the deposits of the old Burro Mountain Copper Co. near Leopold, among which are the East ore body, the Sampson ore body, and several smaller deposits. The second group includes the deposits of the old Chemung Copper Co. near Tyrone, among which are several more or less distinct veins and blocks of ore.

The projections to the surface together with numerous cross sections of these deposits are shown in my report on the Tyrone district (7).

The mines near Tyrone are developed by two shafts in Niagara Gulch. A third shaft to the west did not disclose any considerable body of ore. The Breccia ore body, in a country rock of brecciated granite and intruded porphyry dikes, is about 750 feet east of shaft 3 (7, pp. 41–44).

A prominent vein system overlies the Breccia ore body. The deposit, though following a fault nearly at right angles to the principal fissures, is limited at its ends by two very prominent zones of movement. This broken ground probably collapsed when the crust was distended during intrusion.

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The principal ore bodies lie within a northeastward-trending zone of fracture between Leopold and Tyrone. They are very irregular in size and shape, ranging from roughly blanketlike masses, grading upward into oxidized ground and downward into primary pyrite, to strong veins or shear zones which are likewise barren near the surface and too lean to be of value below, where chalcocite gives way to primary pyrite.

The East ore body, about 700 feet long and 600 feet in greatest width, related to two strong fractures, is typical of the blanket type. At top and bottom the body has little horizontal extent, but it swells notably at the middle, the form being controlled somewhat sharply on the west and northwest by the St. Louis and North veins respectively. To the east and south the ore merges into the country rock.

The so-called "flat veins" of the Chemung group are typical of the shear-zone type. Here strong central anastomosing veins constitute, with the wall rock, profitable ore bodies. The richer bodies near Leopold are roughly cigar-shaped.

Probably all these ore bodies were localized by the presence of an appreciable greater than average amount of primary chalcopyrite.

Two major groups of developed ore bodies may be recognized. One of these comprises the deposits of the old Burro Mountain Copper Co. near Leopold, among which are the East ore body, the Sampson ore body, and several smaller deposits. The second group includes the deposits of the old Chemung Copper Co. near Tyrone, among which are several more or less distinct veins and blocks of ore.

The projections to the surface together with numerous cross sections of these deposits are shown in my report on the Tyrone district (7).

The mines near Tyrone are developed by two shafts in Niagara Gulch. A third shaft to the west did not disclose any considerable body of ore. The Breccia ore body, in a country rock of brecciated granite and intruded porphyry dikes, is about 250 feet east of shaft 3 (7, pp. 41–44).

A prominent vein system overlies the Breccia ore body. The deposit, though following a fault nearly at right angles to the principal fissures, is limited at its ends by two very prominent zones of movement. This broken ground probably collapsed when the crust was distended during intrusion.

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The Lordsburg district, New Mexico[1]

By Samuel G. Lasky
United States Geological Survey, Washington

General features

The Lordsburg district is in Hidalgo County, southwestern New Mexico, 2 to 10 miles southwest of Lordsburg, a town on the main line of the Southern Pacific Railroad and on United States highway 80. The district is in the northern part of the Pyramid Mountains, one of the isolated desert ranges typical of the Mexican Highland of the Basin and Range province. It includes two contiguous subdistricts—the Virginia district, in the low bare hills at the extreme north end of the range, and the Pyramid district, to the south. The copper deposits are in the Virginia district and belong to the copper-tourmaline type of the deep vein zone. The deposits in the Pyramid district have been mined for silver.

Prospecting in the Lordsburg district began about 1870, when silver was the metal chiefly sought. During the present century mining has been done principally for copper, and the production of other metals, chiefly gold and silver, has been largely incidental. The total production of the district, almost all from one vein, the Emerald, and one mine, the Eighty-five, has a value of about $18,500,000. This mine was abandoned on January 1, 1932, since when the district has been inactive. The ores are of low grade but highly siliceous, and large-scale operations in the district were due in great part to the need for siliceous fluxing ores at nearby smelters.

Geology

The rocks of the Virginia district consist chiefly of basaltic andesite and associated volcanic breccias, in part intrusive, all intruded by an irregular stock of granodiorite. The granodiorite generally has a dark fine-grained border, about 15 feet in maximum width, which contains many magnetite and augite grains, apparently xenocrysts derived from the invaded andesite. Granodiorite porphyry and aplite dikes cut the parent mass. Later volcanic rocks fringe the district and pass under the adjacent desert alluvium.

The geologic ages of the different rocks are as yet uncertain, but the later volcanic rocks are probably mid-Tertiary (Miocene), as are most lavas of the Mexican Highland and the southern Colorado Plateau. The granodiorite is presumably late Cretaceous or early Tertiary, like most similar intrusives of the southwestern United States, and accordingly the andesite and associated rocks may be Upper Cretaceous.

[1] Published by permission of the Director, U. S. Geological Survey. Based chiefly on an underground study of the mines of the district. A survey of the entire district was made later, and a report entitled "Geology and ore deposits of the Virginia mining district, Hidalgo County, New Mexico," is in preparation.

Erosion has probably removed only a few hundred feet from the granodiorite stock. The contact is highly irregular, as shown in figures 37 and 38.

Fault fissures are abundant and are confined chiefly to two zones. (See fig. 37.) Most of the fissures are premineral and have bold, wall-like siliceous vein outcrops. They strike generally northeast and east, forming two rough sets, but members of each set join and cross members of the other and change from one trend to the other. At least five periods of faulting have been definitely recognized. Movement has been small and nearly horizontal. The cumulative net displacement along the Emerald vein, one of the strongest faults in the district, hardly exceeds 150 feet. (See fig. 38.) Several transverse faults offset the veins slightly—20 feet at most. Movement along them has been nearly parallel to the dip, contrasting with the strike movement of the early faults. They are either barren or only slightly mineralized, so that their outcrops are vague. All the faults dip steeply, the dip ranging from vertical to 70° on either side.

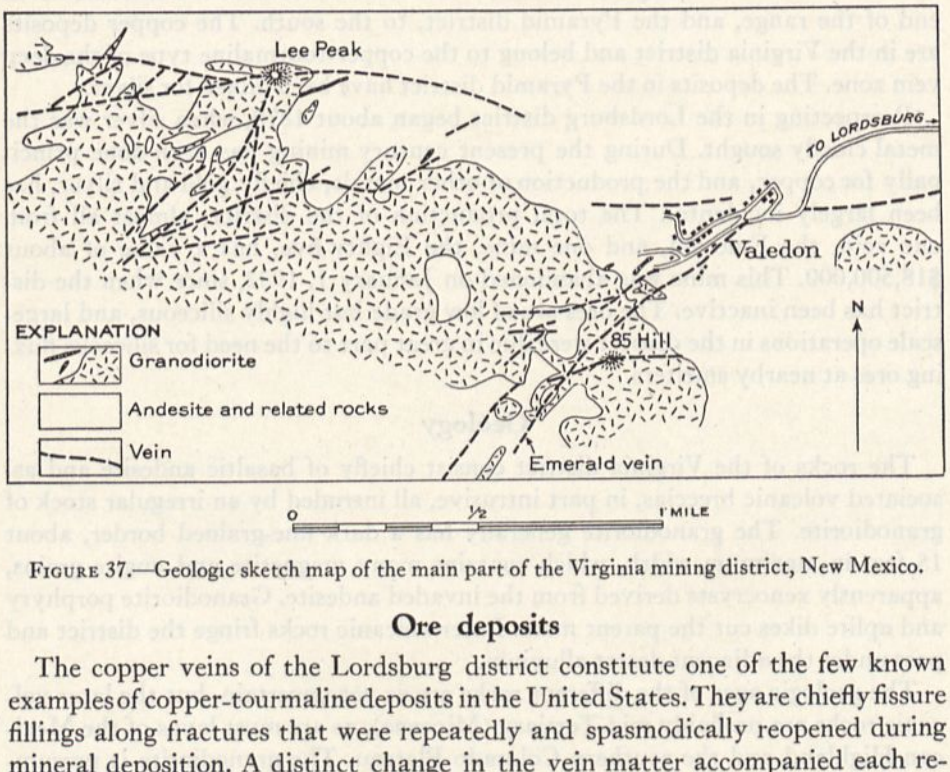

FIGURE 37.—Geologic sketch map of the main part of the Virginia mining district, New Mexico.

Ore deposits

The copper veins of the Lordsburg district constitute one of the few known examples of copper-tourmaline deposits in the United States. They are chiefly fissure fillings along fractures that were repeatedly and spasmodically reopened during mineral deposition. A distinct change in the vein matter accompanied each reopening, resulting in shoots within the vein in which one or another characteristic group of minerals predominates. At no stage except possibly the first were the fissure openings completely filled, and the composite filling is generally vuggy and drusy, so that mineral sequences are fairly clear. Hypogene leaching removed breccia fragments, apparently of altered wall rock, from parts of the vein, leaving a boxwork of vein matter that perfectly preserves the shape of the leached fragments.

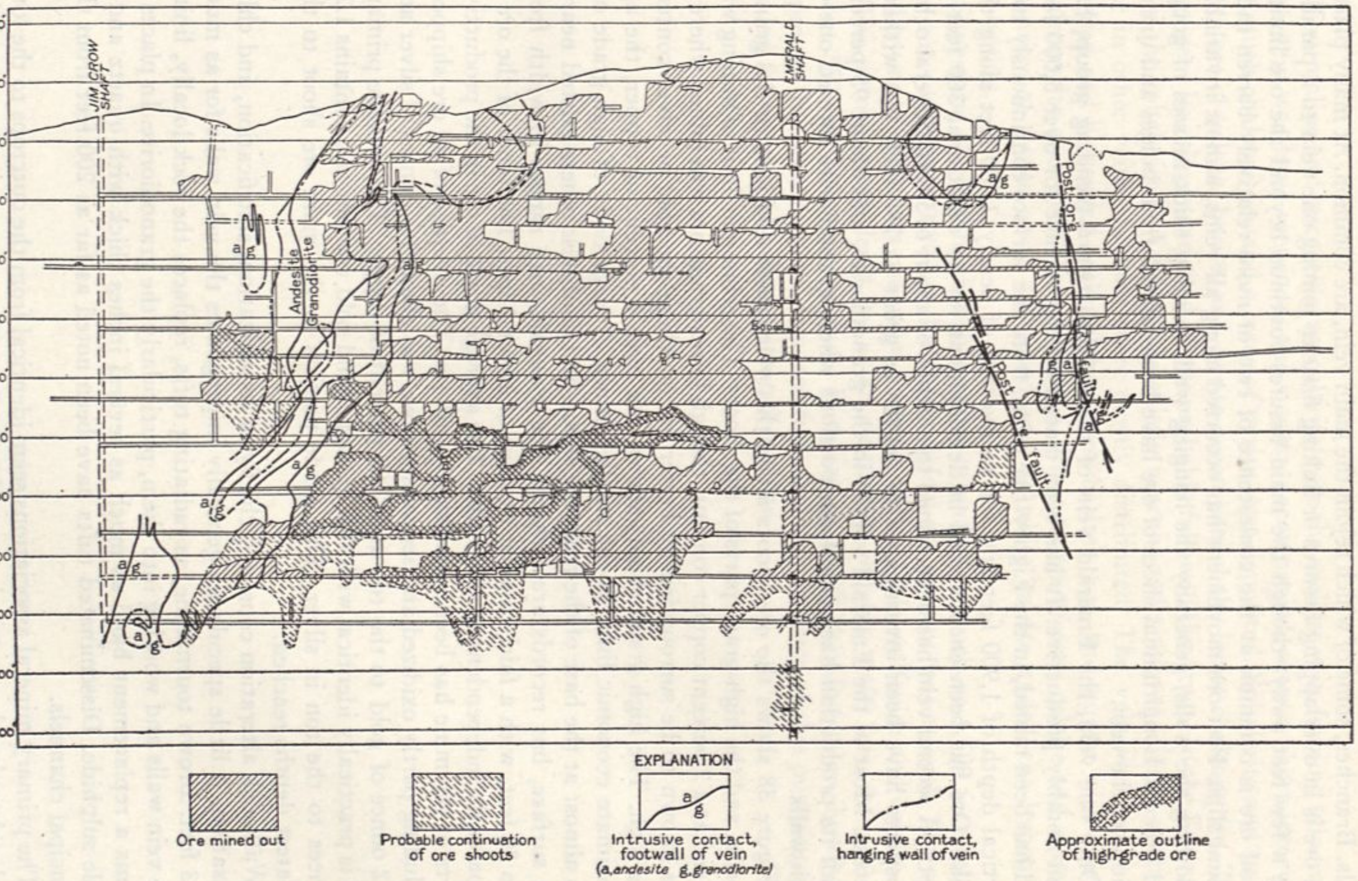

FIGURE 38.—Vertical projection of Emerald vein, looking northwest, Lordsburg, New Mexico.

The veins are typical shear linkages and sheeted zones, which fray out at the ends. Branches, some of which rejoin the main vein, are common. At many places the ore is in overlapping fissures or linking fissures joining one vein to a parallel one a few feet away, though the main fissures continue beyond the ore limits. Good ore is common at the coalescence of two or more relatively barren individual slips. Post-ore movement has occurred along all veins, almost invariably following the walls, generally the hanging wall, forming thick masses of gouge and breccia. Longitudinal slices of ore have been faulted from bulges and undulations of the vein.

Only one vein, the Emerald vein of the northeastward-trending group, has been notably productive. It has been traced on the surface for over 5,000 feet and has been mined, in the Eighty-five mine, from the surface continuously to a vertical depth of 1,900 feet and for an average of nearly 2,300 feet along the strike. Ore has been encountered in development for an additional 300 feet of depth. A second vein has been mined to a depth of about 675 feet. Several other prospects have been investigated to depths as great as 750 feet, but without success. Most of the Emerald vein is in the granodiorite, and about 95 percent of all its production has come from portions where granodiorite formed one or both walls.

Figure 38 shows the ore shoots along this vein, their relations to the granodiorite, and the high-grade parts of the shoots. The economic limit of mining was placed at a 2 percent copper content, though lower-grade ore was mined where it was known to be surrounded by better ore or where the gold or silver content was high. The high-grade shoots shown run over 4 percent of copper, the approximate economic limit in the smaller mines. A large body of high-grade ore lies almost at the base of the main ore shoot, and doubtless others existed nearer the surface, but records are lacking. The Emerald vein ranges in width from 2 to 30 feet, with a fairly regular average of about 5 feet. The tenor of the ore is apparently independent of vein width. The average grade of ore in the productive parts of the mine has been remarkably uniform. The average of all ore shipped, including partly oxidized and secondary ores, was about 1.7 ounces of silver and 0.12 ounce of gold to the ton and 2.85 percent of copper. The average primary ore is practically identical with this in copper and gold content and contains 1.23 ounces to the ton in silver. This grade persists in the main ore shoot to the greatest depths reached.

Wall-rock alteration consisted chiefly of sericitization, silicification, and chloritization. A little specularite generally impregnates the vein walls for as much as 3 feet. Brown tourmaline, as radiating tufts, replaces the rock locally, lining the vein walls and working into them, particularly the granodiorite. In places it forms a replacement band as much as several inches thick with quartz and a little sulphide. Disseminated tufts have been noted as far as 200 feet from the principal channels.

The primary mineral associations seem identical from the outcrops to the lowest level explored, a vertical range of 2,200 feet. The approximate average mineral composition of the ore shoots is, quartz, 65 percent; chalcopyrite, 7.8 percent; pyrite, 4.3 percent; calcite, 4.5 percent; specularite, 2 percent; sphalerite, 1.0

percent; galena, 0.4 percent; tourmaline, barite, and altered wall rock, 15 percent.

Tourmaline and micaceous specularite were the earliest vein-forming minerals. The vein was later reopened, and quartz, accompanied, after a short interval, by much chalcopyrite and a trace of pyrite, was deposited. Sphalerite and small amounts of galena, barite, and pyrite accompanied the latest chalcopyrite. The hypogene leaching mentioned above probably followed this stage. In the Emerald vein the sphalerite and galena are chiefly near the andesite-granodiorite contact, but in other veins they are more evenly distributed. The vein was again reopened and brecciated early in the galena-barite stage, and quartz with a little chalcopyrite and pyrite was deposited. Pink manganiferous calcite and a small quantity of pyrite came next, and gray to white calcite ended the hypogene deposition.

Supergene alteration, though erratic, extended as much as 1,500 feet below the outcrop, about 1,200 to 1,400 feet below the present water level. The secondary suite comprises the usual minerals with a little wulfenite and calcite.

The natural water level lies at an altitude of roughly 4,400 feet, from 50 to about 550 feet below the surface. Pumping at the Eighty-five mine, however, depressed the water several hundred feet, and the influence of this pumping extended for at least 1½ miles in some directions.

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The natural water level lies at an altitude of roughly 4,400 feet, from 50 to about 350 feet below the surface. Pumping at the Eighty-five mine, however, depressed the water several hundred feet, and the influence of this pumping extended for at least 1½ miles in some directions.

Minor copper-producing districts of New Mexico [1]

By A. H. Koschmann
United States Geological Survey, Washington

Magdalena district

The Magdalena district (1, 2), on the west side of the Magdalena Range, comprises much-faulted Carboniferous formations resting on a pre-Cambrian basement and covered in part by Tertiary volcanic rocks. These formations are cut by small stocks of monzonitic rocks and by later lamprophyre and rhyolite dikes.

The principal ore deposits of the district are replacement bodies in Mississippian limestone. They lie along fissure zones that extend southward in steplike arrangement from the principal monzonite stock. Near the monzonite contact the ore bodies contain considerable magnetite and specularite, with associated contact-metamorphic silicates and considerable massive cupriferous pyrite; but the ore bodies consist mainly of large shoots of massive zinc-lead-silver sulphide ore. The upper parts of the deposits are oxidized and have supplied argentiferous lead carbonate ore and high-grade zinc carbonate ore. The output of the district from 1904 to 1930 includes gold valued at $19,367, 777,872 ounces of silver, 8,783,551 pounds of copper, 44,340,284 pounds of lead, and 224,623,102 pounds of zinc.

Pastura district

The Pastura district (3, 4) lies about 8 miles northeast of Pastura, in the east-central part of the State. The formations here consist of about 150 feet of shale and sandstone of Triassic age, overlying Permian sediments. The ore is a flat-lying bedded deposit in the medium-grained gray Santa Rosa sandstone, of Triassic age. The irregular ore body is from 2 to 25 feet below the surface and ranges from 12 to 20 feet in thickness. The floor and roof are sharply defined. The floor consists of clay, but the roof ranges from clay to cross-bedded sandstone. The ore body is about 1,500 feet long and 300 feet wide, and the main trend is about parallel with the strike.

The ore mined averages about 4.8 percent of copper. An average analysis of a 6-month composite sample assayed 1.7 percent of zinc and 0.2 ounce of silver to the ton, in addition to the copper. The ore comprises about 96 percent carbonate, about 3.5 percent sulphide, and nearly 0.5 percent silicate. From July, 1925, to August, 1930, when operations were suspended, the district produced 54,661 tons of ore, which contained about 5,000,000 pounds of copper.

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United States Geological Survey, Washington

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Pastura district

The Pastura district (3, 4) lies about 8 miles northeast of Pastura, in the east-central part of the State. The formations here consist of about 130 feet of shale and sandstone of Triassic age, overlying Permian sediments. The ore is a flat-lying bedded deposit in the medium-grained gray Santa Rosa sandstone, of Triassic age. The irregular ore body is from 2 to 25 feet below the surface and ranges from 12 to 29 feet in thickness. The floor and roof are sharply defined. The floor consists of clay, but the roof ranges from clay to cross-bedded sandstone. The ore body is about 1,500 feet long and 300 feet wide, and the main trend is about parallel with the strike.

The ore mined averages about 4.8 percent of copper. An average analysis of a 6-month composite sample assayed 1.7 percent of zinc and 0.2 ounce of silver to the ton, in addition to the copper. The ore comprises about 96 percent carbonate, about 3.5 percent sulphide, and nearly 0.5 percent silicate. From July, 1925, to August, 1930, when operations were suspended, the district produced 54,641 tons of ore, which contained about 5,000,000 pounds of copper.

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Copper in Oregon[1]

By James Gilluly

United States Geological Survey, Washington

The copper deposits of Oregon occur in two widely separated areas, one in the extreme eastern part of the State, in the Blue Mountains, the other in the southwestern part, in Josephine, Jackson, and Douglas Counties. The combined production of the State can hardly have exceeded 25,000,000 pounds of copper, over two-thirds of which came from the Blue Mountains and over half from one mine, the Iron Dyke.

Blue Mountains

The Blue Mountains of eastern Oregon rise to altitudes of 8,000 to 10,000 feet and expose Mesozoic and Paleozoic sediments and metamorphic rocks in the midst of the great Tertiary lava field of the Columbia Plateau. These rocks have been intruded by large batholithic masses of gabbro, diorite, and quartz diorite of unknown but probably Jurassic or Cretaceous age. The copper deposits are assembled near these intrusive masses and are no doubt of igneous affinities.

The Iron Dyke mine is near Homestead, in the canyon of the Snake River, and exploited, for somewhat over a decade ending in 1927, a series of mineralized shear zones and replacement bodies in Permian greenstone. A little limestone occurred in the mine, and part of the ore is said to have been formed by replacement of it. The principal minerals were chalcopyrite, pyrite, and a little sphalerite in quartz gangue. This mine produced about 15,000,000 pounds of copper before being shut down. Similar but hitherto unproductive deposits are present near Keating, some 30 miles west of Homestead. Copper has also been produced in small amount from the chalcopyrite-tourmaline deposits and from cobaltiferous veins in meta-andesite near Prairie City, in the southwestern part of the Blue Mountains.

Southwestern Oregon

The largest copper deposits so far exploited in southwestern Oregon extend from the vicinity of Riddle southward to the California line in a belt that includes the Galice, Kerby, and Takilma districts. For the most part the country rocks are greenstone, serpentine, and schist, chiefly of Paleozoic age, and the deposits are closely related to diorite, gabbro, and peridotite intrusions, presumably of Mesozoic age.

Many serpentine areas contain numerous lenslike or boulderlike masses of magnetite and native copper, some concentrated along shear zones. The hitherto most productive deposits are near Takilma and consist of chalcopyrite, cubanite, pyrite, and pyrrhotite in a quartz-calcite gangue along shear zones in gabbro, peridotite, and serpentine. Sorted shipping ore has run from 5 to 13 percent of copper with a little gold and silver. Near Riddle occur some ore bodies of bornite with subordinate chalcopyrite, tennantite, galena, and sphalerite in a shear zone in greenstone.

[1] Published by permission of the Director, U. S. Geological Survey.

Although many cupriferous deposits are known in the State, no ore body demonstrably destined to be an important factor in supplying the metal in the near future has yet been developed.

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Copper deposits at Bingham, Utah

By John M. Boutwell

Consulting geologist, Salt Lake City, Utah

Introduction

At Bingham Canyon, Utah, extensive deposits of low-grade copper ore occur disseminated throughout large irregular stocklike masses of monzonite and to a minor extent in adjacent sediments. This ore is mined by the Utah Copper Co. by steam shovel through an open cut, beyond which it has been explored laterally by underground workings and in depth by diamond drilling. The enormous tonnage of ore produced is concentrated in the company's nearby flotation mills at Magna and Arthur, and the concentrates are smelted at the adjacent Garfield plant of the American Smelting & Refining Co. This ore body, the mills, and the copper smelter, commonly regarded as the largest in America, embody the latest and most economic practice in open-pit mining and copper metallurgy.

The present condensed statement covers the more essential features of the geology of these copper deposits, the mining methods, and the ore reserves.[1]

Geography

The Bingham mining district is on the east slope of the Oquirrh Range 26 miles southwest of Salt Lake City, Utah. (See fig. 39.)

The Oquirrh Range, flanked on the east and west by broad deserts occupying deeply waste-filled intermontane valleys and on the north by Great Salt Lake, is the easternmost of the desert ranges. The portion of the range visible today rises above the valley fully 4,000 feet, to an altitude of 9,000 feet. Both eastern and western slopes are deeply incised by narrow, steep-sided canyons, one of the larger of which is Bingham Canyon. Precipitation, comparatively heavy for a desert range, affords deep snows in winter, causing serious snowslides and a heavy spring run-off.

Mining operations

History (1).—The history of the Bingham district is a succession of epochs of mining ores of gold, of lead, and of copper, following advances in transporta-

[1] The generous courtesy of the Utah Copper Co., extended through the vice-president and general manager, Mr. D. D. Moffat, in facilitating inspection of the mine and plant and in freely furnishing information for use in this statement, is gratefully acknowledged.

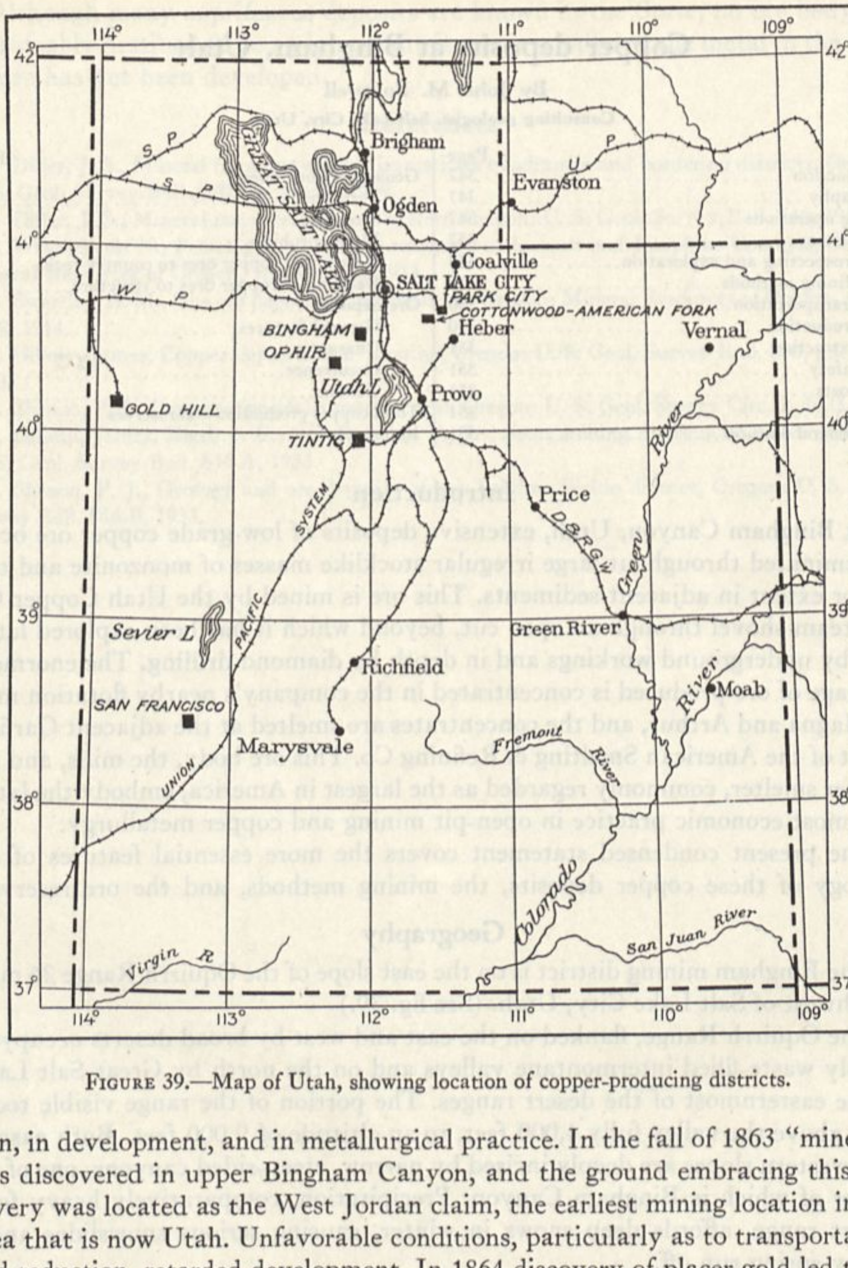


FIGURE 39.—Map of Utah, showing location of copper-producing districts.

tion, in development, and in metallurgical practice. In the fall of 1863 "mineral" was discovered in upper Bingham Canyon, and the ground embracing this discovery was located as the West Jordan claim, the earliest mining location in the area that is now Utah. Unfavorable conditions, particularly as to transportation and reduction, retarded development. In 1864 discovery of placer gold led to an epoch of placer mining, which lasted until 1871 and yielded $1,000,000; later mining has increased this total to $1,500,000. The new activity in gold mining incident to the present business depression has reawakened interest in exploring Bingham Canyon gravel for placer gold. Mining of lead-silver ores, facilitated by railroad transportation afforded by the completion of the Union Pacific and Central Pacific lines in 1869, extended through the district. By 1921, further stimulated by a rise in the price of lead, 21 mines were producing lead ore, and, barring certain interruptions, development of silver-lead ores has continued until the present time. Late in the seventies and early in the eighties, after temporary exhaustion of lead carbonate ores, special attention was directed to saving gold remaining in the oxidized upper portions of ore shoots. By the end of 1882 four stamp mills were in operation, but the savings did not warrant continuance.

In 1896, at the Highland Boy mine, experimental treatment of the low-grade copper ores was undertaken, and active exploration resulted in the discovery of numerous large shoots of low-grade pyritic copper ore. Consolidations of properties, installation of aerial trams, and erection of copper smelters followed.

In 1895–1903 the possibilities of the disseminated ore in monzonite were investigated, systematic exploration and development of these ores by churn drill and underground workings was regularly begun, and extensive bodies of disseminated ore were proved. Through persistent trials successful treatment by flotation and recovery from these low-grade ores was attained. In 1904 the Copperton mill began operating, in 1905–8 the Magna mill was erected, and in 1910 the Arthur mill was acquired and remodeled. These mills operate on low-grade open-cut copper ore mined at Bingham. Upon the completion of large mill capacity by the Utah Copper Co., in 1907, large-scale operations in mining and milling these low-grade disseminated ores were undertaken, and these operations have been continued to the present day. The present daily capacity of the Arthur mill is 28,000 tons, and of the Magna mill 32,000 tons—a total of 60,000 tons of sulphide ores.

Prospecting and exploration.—Early prospecting was carried on by underground workings. Later diamond drilling failed to yield reliable samples, giving a wide variation between core and sludge samples. Accordingly churn drilling has been adopted and is utilized regularly as the most reliable method of prospecting, exploration, and determining ore reserves. Electrically operated drills of standard rig (slightly modified) are used. Holes extend 1,000 or 1,500 feet in depth. An accurate sample is considered the primary requisite. Holes are drilled at corners of equilateral triangles regularly 400 feet apart, or in particular conditions 200 feet.

Mining methods (9).—Mining this disseminated ore in the monzonite mass calls for stripping a quartzitic capping and breaking down the mineralized walls enclosing an extensive pit, disposing of waste, and transporting an enormous tonnage to reduction plants. Both quartzite capping and monzonite ore break readily into innumerable small pieces and so require a minimum of secondary blasting. Under average conditions in selling price of copper, recovery in percentage of gross metal, and cost of producing a pound of copper, the line between ore and waste is a copper content of 0.6 percent. The average thickness of capping to be removed is 115 feet (giving a ratio of 1 of stripping to 2 of ore), and to date more than 100,000,000 cubic yards of capping has been removed. The underlying mass of mineralized monzonite to be mined is, broadly viewed, in the form of a cylindrical or oval body 6,000 feet long, 4,000 feet wide, and 2,000 feet deep.

The operation thus involves mining a cylindrical, nearly vertical mass of homogeneous, easily broken ore. The position of this body in the mountain side determines the best method for mining to be a regular open-cut system. Mining operations were begun along the high, steep west wall of Bingham Canyon. In removing ore a pit was developed; recently similar operations were started on the east side of the canyon, so that this pit is assuming the form of a complete circle or oval. When operations have been completed the resulting elongated bowl-shaped excavation will be more than 8,000 feet long, 6,000 feet wide, and 2,500 feet deep. Under this open-cut system, according to the determining slopes of pit walls, 580,000,000 tons can be removed. The ore then remaining, after about 40 years of open-cut mining, is expected to be mined by caving methods.

The excavating operations are conducted on a series of about 30 contouring terraces or benches. These rise from the present bottom of the pit, at an altitude of 6,340 feet, to the present top of the pit, 1,500 feet higher. The bench heights range from 40 to 70 feet, and the widths from 30 to 450 feet, with an average of 100 feet. Experience proves that the most economical bench height for this pit is 40 to 50 feet.

Toe drilling by reciprocating air drills along the base of slopes (preferably well ahead of the blasting) produces holes 20 to 25 feet deep at 15-foot intervals along a 200-foot front. Any ore remaining unbroken by these toe shots is removed by drilling additional holes three-fifths of the distance up the bank horizontally. Any masses of boulders still remaining are broken by "dobie" (mud cap) blasting of block holes, and the face is then trimmed of loose rock by hand bars.

Loading is accomplished by electrically operated 90- to 100-ton railroad-type shovels, mounted on caterpillar tractors. The shift from rails to caterpillar tractors in 1923 is regarded as the greatest advance in shovel practice in the last 20 years. It at once greatly facilitated movement and reduced labor, with a marked reduction in operating costs and increase in efficiency. In 1923, with the former railroad-type steam shovels with 3½-yard dipper, average loadings were 2,350 tons of ore to the shovel shift; in 1928 the average shovel loading by electric shovels mounted on caterpillars with 4½-yard dipper was 3,966 tons of ore, the average capacity of the shovels being 600 tons an hour. In 1932 a record was established of an average of 4,515 tons of ore loaded to the shovel shift, and loadings as high as 7,000 tons to the shovel shift have been made.

Transportation.—The ore is transported by electrically hauled trains on tracks extending along all benches. The 90-ton cars are hauled by 75-ton trolley storage-battery locomotives from the mining levels to main assembly yards. Here the cars are assembled into 50-car trains which are hauled by standard locomotives to the mills. The company operates a total of 151 miles of track, of which 81 miles is in the mine, including 40 miles on the benches.

Production.—During normal operations the daily production averages 40,000 tons, and under emergency demand this is readily increased to 60,000 tons. In addition, daily stripping amounts to 30,000 cubic yards. The maximum tonnage mined in a day is 68,900 tons, and the maximum tonnage milled in a day is 69,200 tons. In April, 1929, the record was made of mining and milling a daily average of 61,744 tons. Up to January, 1931, 110,549,000 cubic yards of capping had been removed, 204,150,000 tons of ore mined, and 3,483,313,000 pounds of copper produced. Besides the copper, up to January, 1929, 1,008,428 ounces of gold and 10,211,257 ounces of silver were produced. The total value of metals extracted up to January, 1929, was $520,100,314.64.

Extraction.—Of the total ore 85 percent is to be removed by shovels, and the remaining 15 percent will be mined by underground methods. Extraction by flotation, concentration, smelting, and treatment of waters percolating through dumps of low-grade ore in precipitation plants is considered to effect a nearly complete extraction. Thus during 1932 the average extraction of the copper content of the ore milled was 93.15 percent, and the resulting tailing averaged 0.0686 percent of copper (9). In the copper-precipitation plant a 98 percent recovery of copper in water is attained, 50 tons of copper a day being saved (8).

Safety.—Enlightened safety methods and first-aid organization provide for investigation of all accidents, distribution of safety information, and systematic safety instruction. As a result, in 1928 the number of accidents per 1,000 men per month was only 3.7, and the time lost per 1,000 man-hours was only 2.9 days. At the reduction plant there were no fatal accidents from August, 1927, to 1931, and at the mines there were none for 35 consecutive months.

Costs.—Through large-scale operations and employment of highly efficient methods the cost of mining operations is held exceptionally low. Thus the cost per foot of drilling a hole 1,468 feet deep by a standard electric drill is, for labor, power, and water, $1.14; for drilling, $13.33; for casing, $3.04; for sampling and assaying, $2.98—a total of $20.49. The direct operating cost per ton of dry ore in 1929, including drilling, loading, transportation, track maintenance, and various mine charges, is $0.1173, of which 60.3 percent was for labor, 1.84 percent for power, and 37.86 percent for power and supplies. In 1928 the operating cost was 77.42 cents a ton. In 1931 the direct stripping costs were 22.15 cents a cubic yard, and average milling costs 39.27 cents a ton. The maximum cost per pound of copper, in 1918, was 14.53 cents; in 1929 the cost had been cut down to 5.93 cents. In 1931 the average cost per pound of net copper on the same basis, including depreciation and general expenses and allowing a credit for gold and silver, was 6.99 cents. Under normal conditions and operations the cost per pound averages about 6 cents.

Geology

General features.—The northern portion of the Oquirrh Range, in which the Bingham mining district is situated, is made of a thick series of siliceous sediments, chiefly massive quartzite with numerous intercalated limestone members, particularly in the lower portion, and a few calcareous and carbonaceous shales, all of Pennsylvanian age. (See pl. 20.) These sediments have been folded, complexly fractured and faulted, and invaded by extensive and numerous masses of monzonite in the form of irregular stocks, dikes, and sills. The calcareous sediments suffered contact metamorphism, and the monzonitic stock has undergone hydrothermal alteration. Throughout the principal stock of monzonite copper ore is disseminated, in adjoining major limestone members replacement bodies of low-grade copper ore with some silver and lead occur, and in certain master fissures traversing both monzonite and limestones are veins of silver-lead-zinc ore. The major output of copper ore is derived from the great body of disseminated ore in monzonite, the replacement bodies of copper ore in limestones having yielded a relatively minor tonnage.

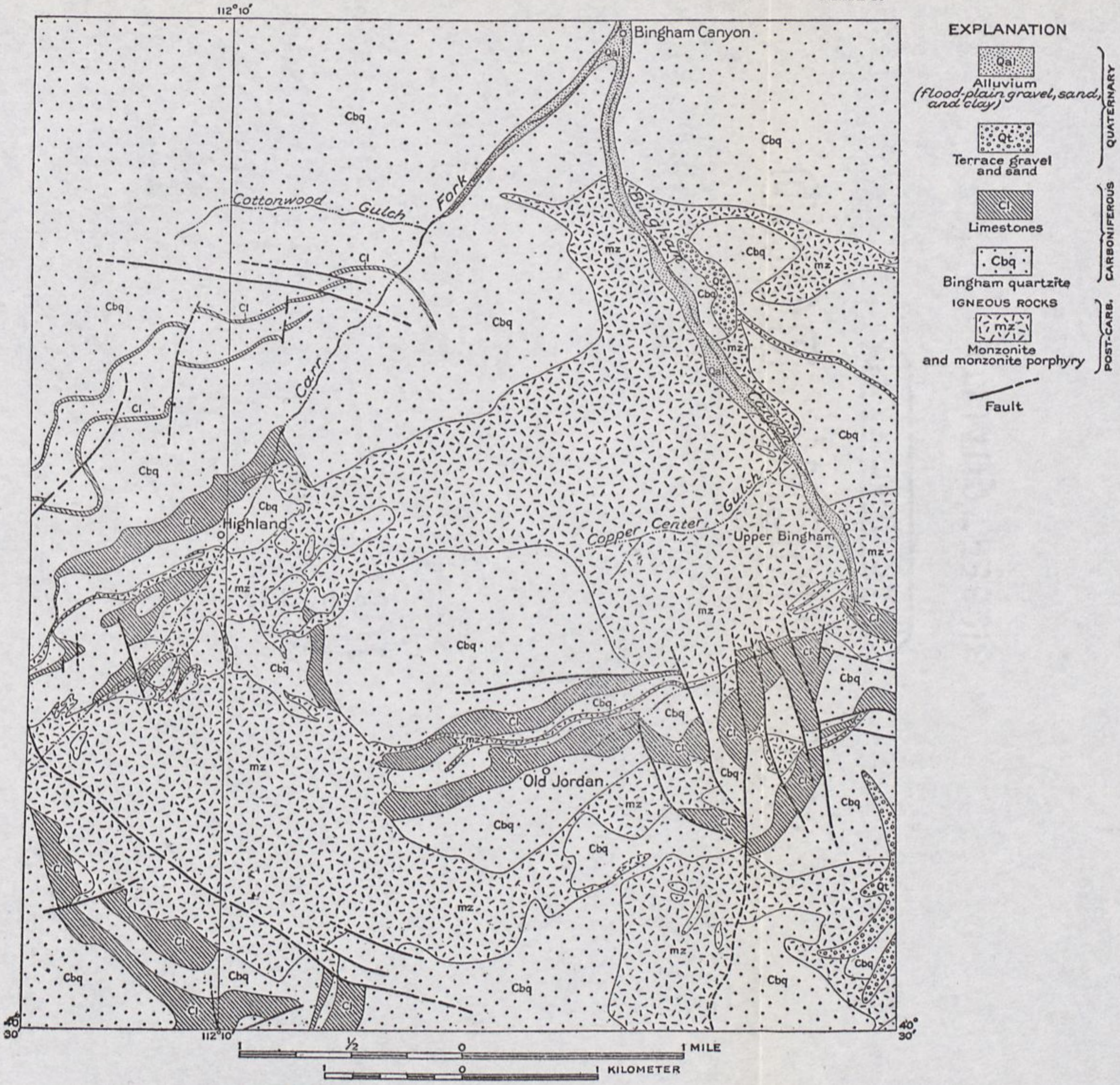
Formations.—The great series of siliceous sedimentary rocks are chiefly dense, medium-grained massively bedded quartzites. Intercalated through this quartzitic series are numerous calcareous beds or lenses, and in the lower portion are about a dozen distinct limestone members, some reaching a thickness of 200 feet, with bands of varicolored chert. In the upper portion of the series calcareous shales and carbonaceous shales are present.

The quartzitic beds of this area, known as the "Bingham quartzite" (1), are a portion of the great siliceous Oquirrh formation (5) of the northern Oquirrh Range. The thickness of this formation is variously regarded as from 10,000 to 15,000 feet (4). Fossils from the limestone members prove the Pennsylvanian (Upper Carboniferous) age of the formation. It is considered broadly equivalent to the Weber quartzite of the neighboring Wasatch Range (3). The ore-bearing series of the Bingham district lies about 4,000 feet stratigraphically above the ore-bearing series of the Stockton district, in the southern portion of this range (5).

The igneous rocks in this district are intrusives of monzonite in the form of stocks, dikes, and sills and extrusives of andesite in the form of flows and tuffs. The monzonite broke indiscriminately across the sedimentary beds, including the quartzites, the intercalated limestone members characteristic of the lower half of the section, and the shales. It assumed the form of two extensive irregular stocks with apparently steep, nearly vertical boundaries—the Bingham mass at Upper Bingham, about 6,000 by 3,500 feet, and the Last Chance mass, 3,500 feet to the southwest, about 3,500 by 4,000 feet. Dikes connect these major masses and, together with smaller stocks, traverse the sediments to the south and east of the main stocks. In certain areas the intrusive took the form of true sills. In general the monzonite in the Last Chance stock, cut by several mineralized fissures, is distinctly fresh, and that of the Bingham stock is generally fractured, altered, bleached, and mineralized throughout. Various facies between the dark fresh monzonite and the light altered monzonite are found. Fragments of basic porphyry in the Utah Copper pit suggest the presence nearby of late lamprophyric dikes cutting the monzonite. The Last Chance vein ore yields silver, lead, and zinc, and the Bingham disseminated ore contains copper.

The fresh monzonite in the Last Chance stock is a dark-gray medium fine-grained rock with subporphyritic to granular texture. The freshest material is composed of biotite, augite, hornblende, orthoclase and plagioclase, magnetite, and small amounts of apatite, rutile, and zircon (1, p. 166; 4, p. 851). The plagioclase feldspars are all acidic, none more basic than andesine (4). Most of the fresh rock lacks quartz, though in some of it a small amount has been observed.

Structure.—The structure of the formations in the Bingham district is that of a shallow syncline that pitches northward and is limited on the west by an anticline and on the east by a steep upturn. This trough is broken by numerous frac-



GEOLOGIC MAP OF THE CENTRAL PART OF THE BINGHAM MINING DISTRICT, UTAH

Based on map by Arthur Keith and J. M. Boutwell (U. S. Geol. Survey Prof. Paper 38, pl. 1, 1905), modified in part from data by R. N. Hunt (Am. Inst. Min. Eng. Trans., vol. 70, fig. 3, p. 861, 1924).

tures and strong fissures, with faulting, of three main trends—northeast, north, and east. The northerly breaks belong to the Basin Range system, and the easterly breaks show pronounced faulting. Breaking up through this structure and occupying the central portion of the trough are the two extensive stocks of intrusive rock, with various minor stocks and tributary dikes and sills. The deepening underground mining development shows that the northeastern and southeastern contacts of the Bingham stock are approximately vertical, the northwest contact dips steeply northwestward, and the southwest contact branches out irregularly in dikes connecting with the Last Chance stock.

Metamorphism.—Through metamorphism (4, pp. 351, 352; 1, pp. 166–168; 8, p. 610) the fresh, tough, dense monzonite has become a light-gray fractured, jointed mass of silica, sericite, and colorless mica with numerous grains of disseminated sulphide. Biotite is the only original mineral remaining, the rock mass is made up largely of granular quartz, the orthoclase and some of the plagioclase have given way to felty masses of sericite, some of the original biotite is represented by bleached colorless mica, abundant secondary mica is developed, and small grains of rutile are fairly abundant. Thus "the typical changes that have taken place in the normal composition of the monzonite during alteration are the almost or quite complete alteration of augite, hornblende, plagioclase, and magnetite and the partial alteration of the orthoclase and biotite to sericite, secondary biotite, quartz, and secondary orthoclase" (4, p. 352). In the walls of veins in the Last Chance stock analysis shows "an unusual and almost complete removal of magnesia and extensive leaching of sodium and calcium. There has evidently been an addition of potassium" (6, p. 610; 1, p. 178).

The metamorphism of the limestone members intercalated in the quartzitic series is most marked in the vicinity of igneous intrusives. It clearly has been induced chiefly by the intrusion and to a comparatively insignificant degree by regional or dynamic influences. Broadly this metamorphism comprises marmarization, some dolomitization, and silicification (1, p. 185). Study of a limestone bed truncated by monzonite shows that normal fresh blue limestone, on approaching the intrusive, passes through transition stages into true marble. Analyses of a series of specimens showing these stages indicate that in the transformation to marble (1, pp. 186, 189) an increase in silica and magnesia and a decrease in calcium and carbon dioxide took place. Lindgren's thorough study of this problem, based on analyses of groove samples cut across wide limestone beds in the Utah Apex mine, afforded an exceptionally accurate and reliable body of facts from which he concluded (7, p. 534) that "as a consequence of metamorphism the siliceous limestones of the Yampa and Highland Boy formations have gained silica, sulphur, iron magnesia, alumina, and soda, and that carbon dioxide and (generally) lime have been carried away . . . silication . . . seems favored by the proximity of the contact with the intrusive . . . metamorphism . . . extends from a few hundred feet to a maximum of 2,000 feet from the igneous contact. The metamorphism was accompanied by the introduction of pyrite and chalcopyrite . . . to a moderate extent. They formed practically simultaneously with the silicates. The ore deposits of importance were formed at a distinctly later stage . . . with the development of silicates, but continuing to form until the temperature had fallen far below the point of silication." As "between dynamic and igneous metamorphism," under dynamic metamorphism "changes are slow... recrystallized rock has little porosity. . . . In igneous metamorphism . . . reactions . . . take place rapidly . . . porosity may develop."

In brief, thorough hydrothermal alteration characterizes the monzonite in which the extensive disseminated copper ores occur, and contact metamorphism marks the adjacent limestone in which large ore shoots of pyritic copper are found.

Relation of copper ores to country rock.—The copper ores of this region occur either in igneous rock or in limestone adjacent to igneous rock. The great body of disseminated copper ore occurs within the Bingham stock of monzonite, practically throughout the intrusive mass. In certain places a small amount of disseminated ore is found in the quartzite immediately adjoining the intrusive, but this does not extend far away from the monzonite. The disseminated copper ore appears to occur most abundantly in those portions of the monzonite which have been fractured, crushed, and altered and to have formed chiefly along fracture or joint planes and subordinately in altered areas immediately adjacent to such planes (1, p. 131).

Large lenticular shoots of low-grade pyritic copper ore occur as replacement bodies within the thicker limestone members in the general contact zone adjacent to the intrusive masses. The intimate association of characteristic silicates, crystalline calcite, and primary sulphides in the metamorphosed walls of these ore shoots indicates their contact-metamorphic relation to the intrusives.

No constant relation between character of country rock and value of copper ore appears to exist. The highest copper content is found in the enriched replacement ore in limestone, and the higher-grade portions of the disseminated ore are found in the most altered portions of the monzonitic stock.

Relation of copper ores to structure.—The remarkably thorough and intense shattering and jointing which characterizes the monzonite of the Bingham stock clearly exerted a favorable influence on the deposition of the disseminated copper ores. So completely has this rock been broken up that it is practically impossible to obtain a hand specimen a few inches across which does not show fracture planes. Such open spaces obviously favored the passage of hydrothermal solutions and deposition from them of sulphide ores. On the other hand, in certain places pronounced movement that produced heavy gouge acted to prevent free circulation of ore-bearing solutions (4, p. 358). In the limestone, fissures near the intrusives appear to have been essential to the formation of valuable bodies of copper ore.

So far as observed, broad geologic structure does not appear to have played an essential part in the primary deposition of the ores, though in a general sense the syncline of the region may have acted in the nature of a catchment basin for descending surface waters and thus facilitated superficial alteration and enrichment of the ores, as the numerous fissures and widespread fractures in a more detailed way undoubtedly did.

Ore deposits

General features.—The principal value of the Bingham output lies in copper, and substantial amounts of silver, lead, zinc, and gold are produced. Most of the copper ore occurs in disseminated deposits in a stock of monzonite, and far less is found in replacement bodies in metamorphosed limestone near monzonite intrusives. The lead and silver ores occur in veins, lodes, and replacement bodies, chiefly in limestone and to a comparatively slight extent in monzonite.

Character.—The disseminated copper ore, including secondary and primary, comprises three main types—the oxidized ore, lying in the superficial portion; the enriched sulphides, constituting the major part of the known ore body, and the mixed enriched and primary sulphides, lying at the deepest known part. The normal disseminated ores are made up chiefly of small grains of sulphide scattered through altered monzonite. In this sulphide ore the copper is carried in chalcopyrite, chalcocite, covellite, and bornite, with which are associated pyrite, magnetite, and molybdenite. The nonmetallic gangue consists of abundant quartz in the form of both grains and veins (4, pp. 357–360). The company finds that of the copper minerals in the ore chalcopyrite comprises 80 percent, chalcocite 9 percent, covellite 7 percent, and bornite 4 percent (9, p. 3). The superficial portion of this ore shows malachite and azurite. The main mass of this disseminated ore is traversed by fissures and fractures, along which intense alteration, silicification, and sericitization have taken place and in which are veinlets carrying galena and sphalerite with some copper and iron sulphides (4, p. 358).

The grade of the ore is remarkably uniform throughout the monzonite mass, both laterally and in depth. As shown in the Utah Copper open cut the mineralization was greatest where the monzonite was most altered. The present known ore averages 1.068 percent of copper. The average copper content of the ore treated in 1932 was 0.973 percent of copper, or 19.46 pounds to the ton (10, p. 6). In some years the gold content has been 0.018 ounce (37 cents) and the silver 0.25 ounce (25 cents) to the ton. In 1932 the value of gold and silver recovered and miscellaneous earnings amounted to 1.06 cents per pound of copper. The average content of gold in the disseminated copper ore is 0.01 ounce to the ton and of silver 0.1 ounce.

The copper ore in the replacement bodies in limestone is essentially chalcopyrite intimately mixed with massive pyrite, minor amounts of tetrahedrite and enargite, and in cases abundant chalcocite, tenorite, and melaconite (1, p. 359). The gangue includes pyrite, marcasite, specularite, and small amounts of pyrrhotite, arsenopyrite, calcite, green garnet, and blende. Traces of gold and silver are present. These ores carried about 3 percent of copper, but the average grade eventually declines in depth. Among the oxidation products the hydrous iron sulphate pisanite occurred abundantly and in this country was first recognized at Bingham. Luckite and mallardite were also first described from this district.

Occurrence.—The disseminated copper ore occurs scattered throughout the mass of a large stock of monzonite. It extends outward sparingly for short distances into the enclosing quartzite wall, farthest along fracture zones. The general shape of this ore body is thus that of a cylinder standing nearly vertical or an oval drum standing on its head. This body of ore, as indicated by company tests, extends along a northeast-southwest axis about 6,000 feet with a width of nearly 4,000 feet and a vertical depth of 2,000 feet.

This great oval drum of thoroughly shattered and jointed monzonite is locally cut by definite fracture zones and fissures. These more broken portions show a lighter color and are marked by greater alteration of the monzonite and higher silicification. Throughout such shattered, altered monzonite the disseminated copper occurs in maximum amount and grade, in the form of grains of the copper sulphides dotting the walls of the fissures and joint planes and to a less degree scattered through the solid body of the rock. In veins and veinlets of quartz and orthoclase (4, p. 357), which traverse this mineralized monzonitic mass, grains of chalcopyrite associated with pyrite and molybdenite occur. A few small veins coursing N. 30° E. through the disseminated ore carry copper and iron sulphides, galena, and sphalerite, and other veins are composed of molybdenite (4, p. 357).

Broadly viewed in connection with superficial alteration, this copper ore occurs in three major zones—the oxidized, enriched, and primary zones, which lie roughly horizontal. The zone of oxidized ores extends from the surface downward 20 to 150 feet, with an average of about 115 feet. The zone of enrichment comprises two parts, the upper part marked by the predominance of the secondary copper minerals chalcocite, covellite, and bornite, extending from the base of the oxidized zone downward about 500 to 600 feet; and the lower part marked by the predominance of primary chalcopyrite with subordinate and decreasing amounts of chalcocite and covellite, continuing irregularly downward about 700 to 800 feet. The primary zone, marked by primary chalcopyrite and the absence of secondary minerals, remains to be definitely determined.

The maintenance of a commercial grade of the disseminated copper ore at depth depends upon enrichment, as the copper tenor of the primary ore falls below the "cut-off" of 0.6 percent. Ore of good grade, however, has been encountered at or near the greatest depths reached by some of the deeper drill holes. Thus in a hole 1,475 feet deep the upper 200 feet showed a copper content of 0.88 percent, from 400 to 600 feet a content of 1.16 percent, at 1,000 feet 0.81 percent, and at 1,400 feet 0.80 percent, with some material of 0.52, 0.78, and 0.54 percent intervening at about 1,200 feet. The deepest hole, which reached a depth of 1,765 feet (altitude 4,800 feet), disclosed at its bottom copper of minable grade. In general, the copper content persists through this ground as a whole with a grade to permit mining, to a depth of about 900 feet below the present lowest mine level, or 1,000 feet below the present assembly yard, or an altitude of 5,440 feet. Depth appears to have brought no change in the content of the precious metals.

Fracturing has exerted important influences on the occurrence of the disseminated copper ore. Thus a strong N. 50° E. zone of fractures dipping 45° NW., coursing entirely across the pit, roughly divides this great ore body into two parts, the lighter-colored, higher-grade part occurring on the northwest or hanging-wall side of the zone, and the darker, lower-grade part on the southeast or footwall side. A few minor exceptions to this general division are seen in certain isolated patches of the darker ore in the hanging wall, chiefly on the north, highest above and farthest away from the main fracture zone. Thus the better grade of copper ore, together with the maximum bleaching, alteration, and silicification, occurs along this major fracture zone and in its hanging wall.

The major fractures in this area show most bleaching and mineralization, pointing to their use as passages. An abundance of chalcocite and covellite grains upon the myriads of joint planes clearly indicates their control in determining the major locus of ore deposition. Certain fissures and faults that traverse the body of disseminated ore may have existed before the ore was deposited, and their planes, and the gouges along them, may have influenced the ore deposition.

Structure played a leading part in determining the form of the ore bodies in the replacement lenses of suphides in metamorphosed limestone near intrusives. Thus the bedded structure of the parent limestone primarily governed the attitude and the tabular form of the replacement bodies. Further, the prevailing structure of the copper shoots in limestone is a bedded structure corresponding to and inherited from the stratification of the country rock. Again, fissures in limestone near intrusives appear to have been essential to the formation of replacement bodies of copper ore.

In horses of limestone included within the monzonite the iron content of the ore shows a decided increase, and the gangue minerals include characteristic contact-metamorphic silicates such as garnet and vesuvianite.

Genesis.—The monzonitic magma forming the Bingham stock rose through the sediments, metamorphosed them, and induced the deposition in adjacent limestones of some copper sulphides. More specifically, this igneous mass appears to have ascended at a point in the north and east part of its present area, vertically on its east side, almost vertically on its north side, advancing upward and slightly southward and breaking upward and westward on the west through the sediments in the form of dikes and sills. Incident to the cooling of the magma, innumerable joints, zones of fracture, and fissures developed in the intrusive, and fissures formed in the sediments. A master fracture zone extended N. 50°–60° E. through the intrusive, and fissures trending N. 30° E., formed perhaps somewhat later, extended through enclosing sediments and to a less degree through the monzonite. Hydrothermal solutions rose from the deep, still uncooled portions of the intrusive, particularly along the master fracture zone and along the passageways in the overlying monzonite, developed abundant quartz, orthoclase, and some sericite, and deposited the primary sulphides of copper and of iron in the form of small grains throughout the mass of monzonite, especially along fracture and joint planes. Outside this central outlet for the highly heated solutions, in the enclosing sediments, primary sulphides of lead, silver, and zinc were deposited in fissures as veins; primary copper sulphides and some lead-silver sulphides were laid down in limestones by replacement; and veinlets of sulphides of lead, silver, zinc, and molybdenum were formed in portions of the intrusive.

The disseminated copper ores thus deposited throughout the shattered, fractured, fissured, and jointed monzonite were attacked by descending surface waters. Iron and copper sulphides were altered to iron and copper sulphates, which oxidized to iron sulphate and stable sulphate minerals and in part broke down into ferric oxide and sulphuric acid (4, pp. 359–360). Some copper carbonates associated with iron oxide resulted, and along favorable channels some oxide of copper and native copper were formed.

Most of the copper in the superficial portion of the disseminated copper ore, however, was carried downward and precipitated in the underlying zone of enrichment. In this zone the primary sulphides, chalcopyrite and to a minor degree bornite and pyrite, were partly or wholly replaced by the secondary sulphides, chalcopyrite, chalcocite, covellite, and probably a little bornite. In the upper part of this enriched zone, where the enrichment was most advanced, the secondary sulphides (chalcocite, covellite, and some bornite) prevailed; but in the lower part the enrichment decreased, consisting in the addition of secondary chalcopyrite alone (4, p. 360). At its downward limit the zone of enrichment gave way to the zone of primary chalcopyrite with some bornite and pyrite.

The replacement copper ores in limestone show a well-defined succession downward: carbonates, oxides, and native copper occur near the surface and pass into secondary sulphides, which in turn give way in depth to primary sulphides. It thus appears that the chalcopyrite and pyrite, with some enargite and tetrahedrite, which were deposited in the limestones (in part contemporaneously with the monzonite intrusion and probably in greater part later, simultaneously with the disseminated ores in monzonite), have also undergone thorough superficial alteration and enrichment. Through surface oxidation the sulphide ore was altered, leaving the gold free (with a small part of the original copper) in the oxidation zone, in a gangue of limonite, and allowing most of the copper to descend. Most of the copper was deposited in the underlying zone of enrichment in the form of chalcocite, tenorite, and melaconite associated with unreplaced cores of chalcopyrite and tetrahedrite. At the downward limit of superficial alteration this zone of highly enriched copper ore gave way to primary chalcopyrite with pyrite, carrying copper and some gold, which in depth became too low in grade to be worked at a profit.

Total copper production and reserves

The following figures (8, 9, 10) show the copper production and reserves of the Bingham district:

Total amount of disseminated copper ore developed in the Bingham monzonite stock..tons..	800,000,000
Total copper production to January 1, 1930, from ores in monzonite ....pounds..	3,378,812,000
Total copper production to January 1, 1930, from ores in limestone ....pounds..	716,459,736
Total copper production to January 1, 1930, from all Bingham ores ....pounds..	3,995,271,736
Total known reserves of copper remaining in monzonite January 1, 1930, 640,000,000 tons of an average copper content of 1.066 percent, which on a basis of 90 percent net extraction would yield ....pounds..	12,280,320,000
Approximate probable reserves of copper remaining in limestone ....pounds..	70,000,000
Total probable copper reserves in monzonite and in limestone in Bingham district..pounds..	12,350,320,000

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Copper in the Tintic district, Utah[1]

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United States Geological Survey, Washington

Geography

The Tintic mining district is in central Utah, about 60 miles south of Salt Lake City (fig. 39), in the central part of the East Tintic Mountains, near the crest of the range, in Juab and Utah Counties. The mineralized area covers about 30 square miles, but most of the production has come from less than 10 square miles. The district includes the towns of Eureka, Mammoth, Dividend, and Silver City. The climate is of the semiarid type characteristic of much of the Great Basin region. The area is accessible both by railroads and by improved highways.

The East Tintic Mountains trend north and form one of the easternmost ranges of the Great Basin in central Utah. The topographic relief is pronounced, the surface dropping steeply from the highest peaks, which reach an altitude above 8,000 feet, to an altitude of about 5,500 feet in Tintic Valley, to the west, and about 4,500 feet in Goshen Valley, to the east. The mountains in the Tintic district are penetrated by a few transverse gulches, but no permanent streams are present.

History and production

The first mining claim in the Tintic district was located in December, 1869, and the district was organized the next spring. Early work was handicapped by poor transportation facilities, lack of water, and to some extent by complex ores. In spite of these handicaps the district has been steadily developed and has been a continuous producer to the present time. The advent of the railroad in 1878 had a stimulating effect, as the chief product has always been first-class shipping ore, especially rich lead-silver ores. Another stimulus was received in 1893, when the Mammoth Mining Co. temporarily solved the water problem by the construction of a 20-mile pipe line and a pumping station with a capacity of 600 gallons a minute.

The latest large discovery in the central part of the district was the Iron Blossom ore zone, in 1905. In 1916 the Tintic Standard, at that time about 2 miles east of the producing area, entered one of the largest ore bodies in the region. The Tintic Standard shaft was started in bleached rhyolite, which overlies the sedimentary beds, and the ore was first encountered in a winze from the 1,000-foot level. This discovery encouraged prospecting beneath the lavas, and other valuable ore bodies have since been developed, especially in the North Lily and Eureka Lilly properties.

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From the time of discovery in 1869 to 1930, inclusive, the Tintic district has produced metals worth $332,006,981. Copper is subordinate in total value to silver, lead, and gold, as shown in the following table:

Nonferrous metals produced in the Tintic district, 1869–1930

	Quantity	Value
Gold .... ounces..	2,030,763	$41,979,573
Silver .... do....	222,197,094	159,417,898
Copper .... pounds..	216,411,477	34,860,679
Lead .... do....	1,602,624,739	93,139,007
Zinc .... do....	30,987,812	2,609,824

From 1921 to 1930, inclusive, the district produced an average of $11,845,012 annually, proportioned as follows:

Average annual production of metals in the Tintic district, 1921–30

	Quantity	Value
Gold .... ounces..	36,786.58	$760,446
Silver .... do....	7,657,920	5,429,525
Copper .... pounds..	3,212,468	452,845
Lead .... do....	75,421,957	5,100,851
Zinc .... do....	1,259,378	97,345

The copper production is largely dependent on the output of other metals, as very little ore has been mined primarily for its copper content. The copper output has ranged from a maximum of about 13,000,000 pounds in 1912 to a minimum of about 3,000,000 pounds in recent years. This decrease has been caused by a decline in production from the older mines, where copper ores were common. In the Tintic Standard and adjacent mines, now among the leading producers, the ores are primarily lead-silver and contain only about 0.2 to 0.3 percent of copper. The district should produce steadily for years to come, especially lead-silver ores, with copper an important accessory.

General geology

The rocks of the Tintic mining district include about 13,000 feet of Paleozoic sedimentary beds, in part overlain and intruded by Tertiary igneous rocks. The table on page 363 gives the Paleozoic formations as defined by Lindgren and Loughlin (2).

The sedimentary beds are folded. An anticline trends northward in the western part of the North Tintic district, and an accompanying syncline appears in the Tintic district and the eastern part of the North Tintic district. The limb common to both these folds has steep to vertical and locally even overturned dips. The western limb of the anticline and the eastern limb of the syncline (fig. 40) have prevailing dips of 30° or less. The structure of the sedimentary beds in the eastern and southern parts of the district is largely concealed by Tertiary igneous rocks—latite, andesite, rhyolite, and basalt flows and dikes, and some monzonite stocks. The eruptions took place long after the sediments had been folded, faulted, and eroded into topographic forms much like those of today. Although the lavas are of premineral age they are very weakly mineralized. Underlying ore bodies occur in places, however, beneath rhyolite where the lavas are especially altered to sericite, chlorite, and alunite and where mineralized fissures and pebble dikes (5) are strongly developed.

Paleozoic formations in Tintic district

Age	Name	Thickness (feet)
Mississippian.	Humbug formation............ Pine Canyon limestone......... Gardner dolomite............. Victoria quartzite............	250 1,000 400–700 85
Upper (?) Devonian.	Pinyon Peak limestone.........	150
Upper to Lower Ordovician.	Bluebell dolomite.............	
Lower Ordovician.	Opohonga limestone........... Ajax limestone................	2,300–2,400
Upper (?) and Middle Cambrian.	Opex dolomite................	
Middle Cambrian.	Cole Canyon dolomite......... Bluebird dolomite............ Herkimer limestone........... Dagmar limestone............. Teutonic limestone............	710±
Middle and Lower (?) Cambrian.	Ophir formation...............	900
Lower Cambrian, possibly in part pre-Cambrian.	Tintic quartzite..............	6,000+

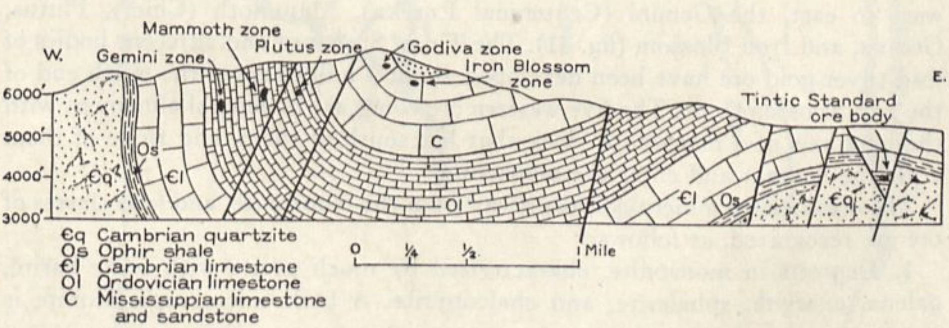

FIGURE 40.—Generalized east-west cross section through central part of Tintic district, Utah. (Modified after R. T. Walker, 1928.)

The most important igneous rock with reference to the ore deposits is the monzonite. This monzonite is intrusive into all other rocks with which it is in contact, and its relatively deep-seated character is accounted for by the fact that at the time of intrusion the present surface was buried beneath 2,000 to 2,500 feet of volcanic rocks. The monzonite stocks are believed to mark the source of the ore deposits.

The stratigraphy and structure are complicated by many faults, which have been referred by Lindgren and Loughlin (2) to five periods, as follows:

1. During folding, compression faulting after the shapes of the folds had been determined. The compression faults strike mostly northeast; the direction of overthrust was eastward.

2. Normal or tensional faulting after folding but before volcanic activity. These tensional faults strike east-west and north-south and are marked by settling of certain blocks and the tilting and convergence or divergence of adjacent blocks.

3. Tensional faulting during volcanic activity. The main faulting occurred around the monzonite intrusions and is attributed to the force of intrusion.

4. Tensional faulting closely following volcanic activity but before mineralization. This faulting may have been caused by shrinkage of the igneous rocks, especially the monzonites.

5. Tensional faulting distinctly later than mineralization. This faulting is probably still in progress in parts of Utah.

Ore deposits

The mineralizing solutions probably rose through fissures in the monzonite, after its consolidation, and spread laterally, especially to the north and east. The solutions moved along fractures and available openings and both sealed the paths of migration and replaced limestone and dolomite at favorable horizons. R. T. Walker (4) has recently advanced the theory that a series of preexisting limestone caves formed parts of the paths traversed by the laterally migrating solutions. Five well-defined zones containing copper as well as other ores have been developed in the central part of the Tintic district. These zones are, from west to east, the Gemini (Centennial Eureka), Mammoth (Chief), Plutus, Godiva, and Iron Blossom (fig. 41). The Tintic Standard and adjacent bodies of lead-silver-gold ore have been developed about 2 miles east of the north end of the Iron Blossom zone. The five western ore zones are in general alinement with the long axis of a monzonite stock that lies south of them, and three of them cross the contact and enter the monzonite.

The ores change mineralogically away from the monzonite, and four classes of ore are recognized, as follows:

1. Deposits in monzonite, characterized by much pyrite with some barite, galena, enargite, sphalerite, and chalcopyrite. A little microscopic alunite is present.

2. The "copper zone," which extends about 1⅓ miles north of the monzonite contact. This zone contains much enargite, a little pyrite, tetrahedrite, famatinite, and gold and silver. Lead is decidedly subordinate. Contact (pyrometasomatic) deposits are present close to the monzonite and therefore coincide with the southern part of this zone, but they are distinctly older than the copper deposits.

3. The "lead-silver zone," which extends about 1½ miles north from the "copper zone." The ores contain mostly rich lead-silver minerals with subordinate copper.

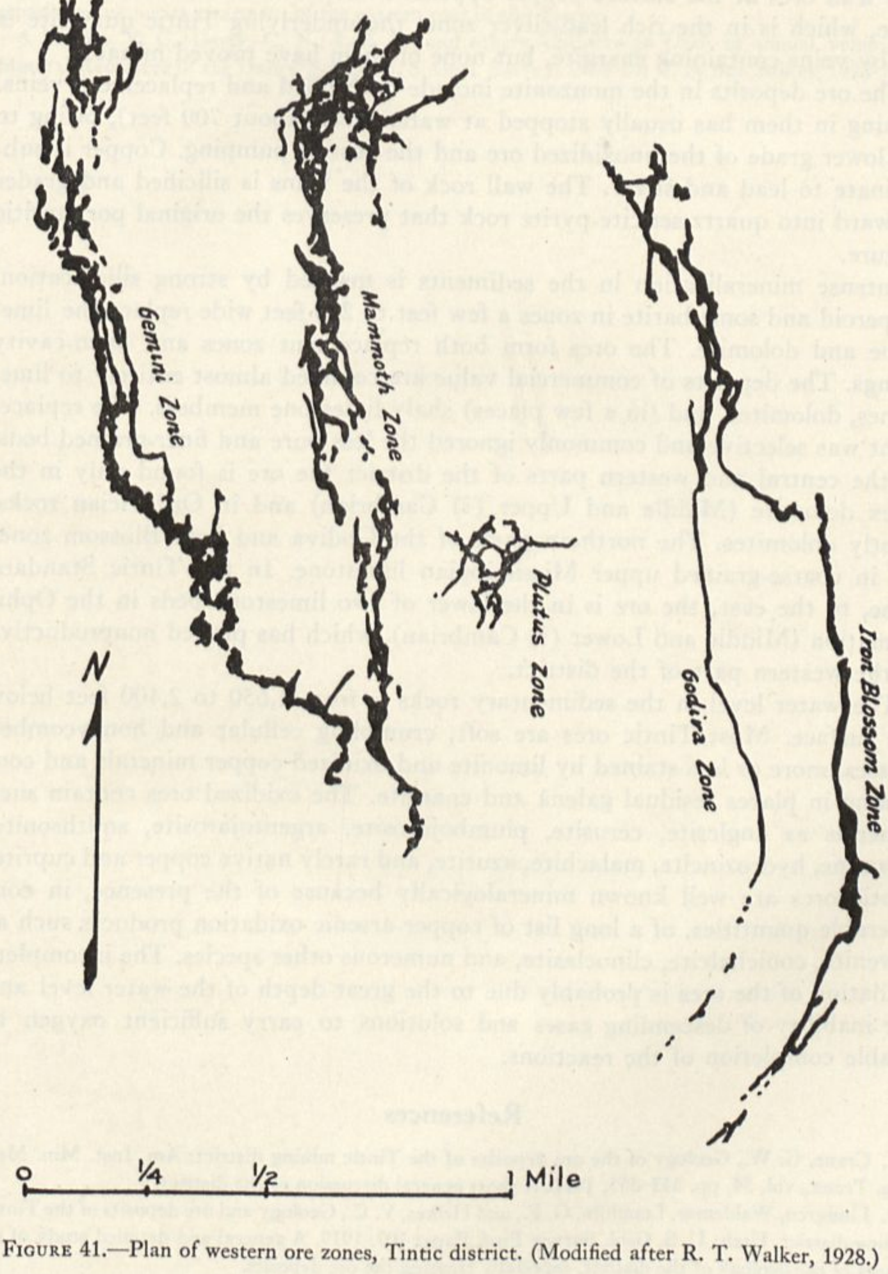

FIGURE 41.—Plan of western ore zones, Tintic district. (Modified after R. T. Walker, 1928.)

4. Farther from the monzonite a zone of feebler mineralization containing chiefly galena and sphalerite, with only a few ounces of silver to the ton.

Zoning of the ores is less marked vertically, but in a few mines that contain only lead ores at the surface copper appears in depth. In the Tintic Standard mine, which is in the rich lead-silver zone, the underlying Tintic quartzite is cut by veins containing enargite, but none of them have proved minable.

The ore deposits in the monzonite include both filled and replacement veins. Mining in them has usually stopped at water level (about 700 feet), owing to the lower grade of the unoxidized ore and the cost of pumping. Copper is subordinate to lead and silver. The wall rock of the veins is silicified and grades outward into quartz-sericite-pyrite rock that preserves the original porphyritic texture.

Intense mineralization in the sediments is marked by strong silicification. Jasperoid and some barite in zones a few feet to 200 feet wide replace the limestone and dolomite. The ores form both replacement zones and open-cavity fillings. The deposits of commercial value are confined almost entirely to limestones, dolomites, and (in a few places) shaly limestone members. The replacement was selective and commonly ignored the less pure and finer-grained beds. In the central and western parts of the district the ore is found only in the Opex dolomite (Middle and Upper (?) Cambrian) and in Ordovician rocks, mostly dolomites. The northern parts of the Godiva and Iron Blossom zones are in coarse-grained upper Mississippian limestone. In the Tintic Standard mine, to the east, the ore is in the lower of two limestone beds in the Ophir formation (Middle and Lower (?) Cambrian), which has proved nonproductive in the western part of the district.

The water level in the sedimentary rocks is from 1,650 to 2,400 feet below the surface. Most Tintic ores are soft, crumbling cellular and honeycombed masses, more or less stained by limonite and oxidized copper minerals and containing in places residual galena and enargite. The oxidized ores contain such minerals as anglesite, cerusite, plumbojarosite, argentojarosite, smithsonite, calamine, hydrozincite, malachite, azurite, and rarely native copper and cuprite. Tintic ores are well known mineralogically because of the presence, in considerable quantities, of a long list of copper-arsenic oxidation products such as olivenite, conichalcite, clinoclasite, and numerous other species. The incomplete oxidation of the ores is probably due to the great depth of the water level and the inability of descending gases and solutions to carry sufficient oxygen to enable completion of the reactions.

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Minor copper-producing districts in Utah[1]

By James Gilluly

United States Geological Survey, Washington

The Park City district, in the Wasatch Range, east of Salt Lake City is a major lead-silver district but has also produced copper, increasingly in recent years. The total output to the end of 1930 was about 54,000,000 pounds, chiefly won from lodes and bedded replacement deposits in upper Paleozoic and Triassic sediments near Tertiary intrusives, and from the igneous rocks themselves (1, 2).

The Ophir district, in the western part of the southern Oquirrh Range, about 12 miles southwest of Bingham, had produced to 1930 about 28,000,000 pounds of copper, largely subordinate to the output of lead and zinc. The copper came chiefly from limestone replacement deposits associated with silicated zones (3).

The Cottonwood-American Fork district, in the Wasatch Range about 20 miles southeast of Salt Lake City, has produced chiefly lead, silver, and zinc, but some 17,000,000 pounds of copper had also been won from the same deposits up to 1930. They are chiefly fissure and bedded replacement deposits in Paleozoic sediments near Tertiary intrusive masses (1).

The San Francisco district, about 180 miles south-southwest of Salt Lake City, has produced more than 41,000,000 pounds of copper, chiefly from pegmatitic disseminated pipes in monzonite but in considerable part from lead-zinc replacement ores in limestone (1, 4).

The Clifton district (Gold Hill), in western Tooele County, has produced somewhat more than 3,000,000 pounds of copper from quartz veins and limestone replacement ores near a monzonite intrusion (5).

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Copper in Washington[1]

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Production

Available records (1, 2) show that since 1899 Washington has produced a little more than 27,000,000 pounds of copper. The yearly production has ranged from several thousand pounds to a maximum of 2,645,022 pounds in 1916. For the decade 1921–30, which may be taken as representing normal pre-depression activity, the average annual yield was somewhat more than 1,000,000 pounds. In 1931 the production fell to about 200,000 pounds, and in 1932 it almost ceased. Considerable silver and a small amount of gold have been recovered with the copper as byproducts, but the exact amounts are not known. About five-sixths of the total has come from two districts of approximately equal production—the Index district, in the west-central part of the State, and the Chewelah district, in the northeastern part. The remaining sixth was obtained chiefly from scattered districts in the northeast and north.

Cascade Range

Index district.—The Index district (3) is in the heart of the Cascade Range and comprises an area of extremely rugged glaciated topography. Altitudes range from 3,000 to 7,000 feet, the climate is comparatively mild, the annual precipitation heavy, and the winter snowfall deep. All but the very steepest slopes are thickly covered with a conifer forest.

The rocks of the Index district and of neighboring parts of the Cascade Range (3, 6, 7, 8) include Paleozoic quartzite, argillite, and schist with lesser amounts of limestone conglomerate and intercalated volcanic rocks, some of which may be as young as Cretaceous. A large area is occupied by an intrusive granodiorite batholith of probable Jurassic age. Tertiary rocks include arkosic sediments, andesitic lavas, dikes of porphyry, diabase, and aplite, and, south of the Index district, intrusive granodiorite.

According to Russell (4) and Smith and Willis (5), after the region had been reduced to a peneplain by late Tertiary erosion, it was uplifted along a north-south axis as a broad arch, from which the present topography was carved by water and ice. Mounts Baker and Rainier and other high peaks are volcanic piles resting upon the arch.

The ore bodies lie along persistent shear and fracture zones in the older granodiorite near its margin. They are hypogene, chiefly disseminated deposits, stringers, and massive lenslike bodies of pyrite, chalcopyrite, and bornite.

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Quartz and calcite form a rather scanty gangue, and in places molybdenite and magnetite are present. Copper carbonates, oxides, and other oxidation products are generally confined to a shallow zone but in places have been found as deep as 400 feet.

In the Sunset, the most productive mine, the ore minerals have partly replaced the granodiorite along seams and fractures in a zone ranging from a few inches to 16 feet in width. Massive lenslike bodies of mixed sulphides also occur along a fault surface. Apparently no supergene enrichment has occurred. The ore is of low grade but is amenable to flotation.

Outlying deposits.—Less developed, generally similar lodes occur above Little Kachess Lake, Kittitas County, near Mount Rainier, and at other places in the Cascade Range. An interesting occurrence of copper in the Olympic Mountains is at the Black and White mine (11), on the North Fork of the Skokomish River, where flakes of the native metal are enclosed in a body composed largely of bementite and other manganese silicates.

Northeastern Washington

Chewelah district.—The Chewelah district (3) is an area of mountainous topography smoothed and rounded by Pleistocene Cordilleran glaciation. The local relief ranges from 1,000 to 3,000 feet, and the summits reach altitudes of 4,000 to 6,000 feet. The area is generally timbered. The precipitation is moderate and the winters fairly cold.

The rocks are chiefly Paleozoic argillite and quartz-mica schist cut by a granitic stock and dikes of lamprophyre. Outcrops are more or less obscured by a patchy mantle of glacial drift.

The ore deposits are veins in the metamorphic rocks near the granitic stock. The largest and most productive mine, the United Silver-Copper, exploits a vein and mineralized shear zone 1,500 feet or more long. Chalcopyrite and tetrahedrite are disseminated through the zone in sufficient quantity to form large bodies of low-grade ore. Included in the zone is a vein from 2 to 12 inches wide and 100 to 200 feet long of silver-rich tetrahedrite (freibergite) containing a little intergrown chalcopyrite and quartz.

Other lodes in the district generally range from a few inches to 7 or 8 feet in width, some of them being expanded locally to 20 or 30 feet. Their ore minerals are chiefly disseminated chalcopyrite with more or less pyrite, quartz, and siderite. Some contain lenslike bodies of massive sulphides. In all the mines oxidation products are confined to the upper levels, and no evidences of downward enrichment have been observed. The ore bodies are hypogene and probably related to the granitic stock. Lamprophyre dikes closely parallel some of the veins but apparently have no genetic relation to the ore.

Outlying deposits.—Outside of the Chewelah district copper-bearing lodes occur sporadically in northeastern Washington and in the northern part of the State as far west as the Cascade Range. The general features of the region are much the same throughout. The mountains have been considerably smoothed by glaciation, and the principal formations are Paleozoic argillites and schists and large intrusive granitic bodies.

In the Danville district (3) bornite, chalcopyrite, and pyrite are disseminated in an altered feldspathic dike that cuts schist. The Bonanza mine, near Springdale, is on a shear zone containing streaks of chalcopyrite. The country rock is schist.

In the Oroville-Night Hawk district (9) overlapping lenses of intergrown marcasite, pyrite, pyrrhotite, and chalcopyrite with a little bornite form a lode in sheared and silicified andesite. A shear zone in granite contains lenses of copper and iron sulphide with a little tetrahedrite.

On Kruger Mountain pyrite and chalcopyrite are sparingly disseminated along fractures and joints in altered basic andesite.

In the Myers Creek district (10) the Paleozoic rocks have been intruded by a quartz-bearing hornblende syenite. Contact metamorphism has altered a bed of limestone to garnet and other characteristic silicates. Chalcopyrite occurs as a scattered intergrowth with the metamorphic minerals and as bunches of considerable size accompanied by pyrite, magnetite, and quartz.

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Sedimentary copper deposits of the Western States

By John Wellington Finch
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In the western United States sedimentary copper is more widely distributed than other metals, probably because it had more sources than silver, lead, or the rarer uranium and vanadium and because it travels more widely in solution. It is generally associated with sedimentary deposits of the other metals (1, 2), and all appear of common genesis.

Characteristics of the beds

The formations are clastic sediments, generally known as the "Red Beds" (9). They accumulated in an arid to semiarid climate and are mostly continental deposits formed by temporary streams and other subaerial agencies (10). Characteristically they contain vegetal remains, silicified in some localities, lignitized in others. Saurian tracks are common, and several localities are famous for vertebrate remains (9, p. 161). Lime cementation is characteristic, and gypsum is common. The gypsum is bedded in the Permian of Texas and New Mexico and the Triassic of Wyoming, southeastern Nevada, and northern Arizona but is disseminated or forms later seams elsewhere. Many of the clastic deposits have been derived from pre-Cambrian rocks. The time of sedimentation was remote from igneous epochs of the Rocky Mountain region.

Characteristics and origin of the copper deposits

Although the copper deposits occur in the Red Beds, they are rarely found in red strata. Possibly the beds that contain them were bleached by the copper-depositing reactions. These deposits differ from hydrothermal deposits in the absence of any related quartz or other gangue. Silicification of woody fossils and the presence of calcite and gypsum are independent of copper deposition. The deposits show no geomorphic, structural, or geographic relation to Jurassic or Tertiary igneous regions—in fact, in areas near the Red Beds deposits the Tertiary magmatic solutions lacked copper. Pre-Cambrian ore deposits in and around the Red Beds region were characteristically copper-bearing. The Red Beds deposits contain copper sulphides, but not with hydrothermal mineral associations, and they were not restricted to special epochs, like hydrothermal ores, but were formed through several long geologic periods. They are so widely distributed and so uniform in character that all must have had a common origin. They were apparently dependent upon local sources of copper that were also local sources of the sediments and were deposited only under special conditions of sedimentation.

The Red Beds rest directly upon pre-Cambrian rocks in western New Mexico (3) and elsewhere (2). The upland areas in which pre-Cambrian rocks were exposed in Red Beds time were in southern Wyoming (12); in Colorado (13, 14, 15), around the west border of the Pikes Peak and other pre-Cambrian batholiths; in the Wichita and Arbuckle Mountains, Oklahoma (16); in the Llano-Burnet uplift, Texas (17); in an extensive highland in western New Mexico (18) that connected northward with the Uncompahgre uplift of Colorado (19); and in the Uinta and Uncompahgre ridges in Utah and Colorado (2, 19). In the Bradshaw Mountain area of Arizona rich pre-Cambrian copper deposits were covered by early Paleozoic beds, but in northern Arizona some copper-bearing pre-Cambrian highland, not now recognizable, appears to have been eroded in late Red Beds time to account for the sedimentary copper.

Factors of sedimentation

The remarkable uniformity and continuity of climatic and tectonic conditions from Carboniferous to early Cretaceous time were factors controlling copper deposition in the Red Beds.

The climatic range was like that of today over the Red Beds territory. The relief was probably somewhat as at present in early stages but much less most of the time. In the higher areas there was moderate rainfall and considerable vegetation, as shown by the great tree trunks and plant fragments washed down and deposited with the beds. At intermediate altitudes highland vegetation extended down intermittent stream routes, and desert flora occupied the ridges. Below this belt valleys expanded into barren flood plains, wide coastal marshes, and shallow marine basins.

The upland and intermediate belts were subject to violent storms and floods that deployed over shifting routes. The floods were dissipated on the desert plains, dropped their coarser loads at varying distances according to the violence of the storms, but spread finer sands and mud over larger areas or discharged them into playas.

In much of the desert today there is no continuous body of ground water. Desert plains are covered deeply by rapidly dumped, coarse rock debris alternating with sand and clay. The coarse discontinuous bodies commonly contain stagnant water. The varying composition of water in wells shows lack of underground communication. Playas in closed basins are underlain to a moderate depth by water-bearing sands highly charged with soluble salts.

Under such conditions of sedimentation, outcrop debris could be carried long distances. Because vein outcrops were in more humid surroundings than the plains, some copper from around the tops of veins may have been redeposited as supergene ore, but probably more escaped in sulphate solutions into stream channels and was carried to the plains by floods. Some was caught by adsorption in muds and clays, and some was left by evaporation. Outcrop fragments, stagnant sulphate solutions, and surface efflorescences were buried when subsequent floods swept over them. Some soluble salts may have been picked up from the surface at times of storms and moved along the plains. Copper traveled from a few miles to 200 miles, as shown by the distribution of deposits with reference to highlands.

Evolution of the copper deposits

Three stages may be assumed in the evolution of the copper deposits—(1) the original deposition of copper with the beds, (2) a long period of deep burial that placed the copper deposits in a reducing environment, (3) a period of reoxidation as erosion exposed them. The deposits were syngenetic in stage 1, epigenetic thereafter.

Stage 1.—The general method of deposition in solution and as fragments (15, 21, 22, 23) has already been suggested. The sediments were derived from extensive highlands generally devoid of copper. There was, however, a localization of copper along slopes heading in areas containing copper outcrops, so the deposits in stage 1 were controlled by position of sources, routes of run-off, and torrential temporary streams. Woody material was protected from normal decay by desiccation. Its tendency was to become silicified if it remained long near the surface, but if rapidly and deeply buried it was lignitized. At ordinary temperatures the organic matter in the beds would not reduce sulphates to sulphides; native copper would be more likely to be precipitated (24), but this is rare in the deposits. Some carbonate might have been converted to chalcocite in ground water, as has been shown by experiment (25), if moderate organic decay evolved some hydrogen sulphide.

Stage 2.—In late Jurassic time the uplands had become peneplains. The late Jurassic, Cretaceous, and later seas deeply buried the 1,500 to 8,000 feet of Red Beds with 5,000 to 10,000 feet of overlying beds. Plant material was converted to coal, and covellite or chalcocite replaced the coal as fast as hydrogen sulphide was produced (3, p. 79). There was some segregation of plant remains during deposition (15, p. 172), and hence some localization of copper in stage 2. Covellite and chalcocite were precipitated, also by the hydrogen sulphide reaction, in seams and lenses of porous rocks. Small amounts of pyrite and chalcopyrite were apparently deposited contemporaneously with the chalcocite (3, p. 79). Some replacement of these sulphides by chalcocite (8, pp. 615, 622) was possibly effected in stage 3. The copper ores of the Boleo mine (26), in Baja California, may have been formed in stage 2 by segregation of copper from beds, partly volcanic, that contained copper when they were laid down.

Stage 3.—In stage 3, which has extended to the present time, copper has accumulated at and near the surface in local bodies of commercial value. Although there is no complete record, the total production from them in six States may have been about 10,000,000 pounds of copper. Remnants of chalcocite are found. Sulphates have migrated from scattered sulphides undergoing oxidation to places of discharge, where evaporation and reaction with lime have generally precipitated shallow bodies of copper carbonates. In some localities (27, 28) plant remains appear to have been lacking, and sulphate solutions entrapped in the sands were never precipitated as sulphides but were finally deposited as silicates and oxides in stage 3.

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El cobre en México

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Descripción sucinta de la geología de México, con referencia especial a las provincias metalogénicas más importantes

Las grandes divisiones fisiográficas que se pueden considerar dentro del territorio mexicano, guardan estrecha relación con las provincias geológicas, y éstas a su vez tienen íntima conexión con la distribución de los criaderos minerales. Con este motivo y a fin de ligar los conceptos, expondremos de acuerdo con lo anotado antes, algunas ideas generales que sirvan para resolver el tema planteado al principio.

El territorio mexicano se compone esquemáticamente de los elementos que a continuación se describen: una gran altiplanicie llamada "Mesa Central" que se inclina suavemente hacia el noreste y que penetra a los Estados Unidos de Norteamérica. Tiene elevaciones cuya altura varía entre 1,500 y 1,200 metros sobre el nivel del mar y está limitada principalmente por dos grandes cadenas montañosas denominadas "Sierra Madre Occidental" y "Sierra Madre Oriental." La primera, que viene desde los Estados Unidos del Norte y entra a territorio mexicano por los Estados de Sonora y Chihuahua, siguiendo hacia el sur la dirección general de la costa del Océano Pacífico, hasta cerca del paralelo 20°, donde voltea hacia el este-sudeste para continuar por los Estados de Michoacán, México, Morelos, Puebla y Oaxaca, conociéndose la dependencia de esta gran cordillera en los Estados de Guerrero y Oaxaca con el nombre de "Sierra Madre del Sur."

La Sierra Madre Oriental tiene también una dirección general paralela a la costa del Golfo de México y va a unirse con la Sierra Madre Occidental en la región de la Mixteca Alta. La vertiente oeste de la Sierra Madre Occidental, es generalmente abrupta y angosta, mientras que la vertiente oriental de la Sierra Madre Oriental tiene pendientes más suaves, siendo esta pendiente más ancha. Las dos zonas que se encuentran entre el pié de las sierras y el litoral, constituyen las planicies costeras, de clima generalmente cálido. La Sierra Madre Occidental continúa por la región del Istmo de Tehuantepec y penetra

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[1] En la preparación de este trabajo, el autor fué ayudado de manera empeñosa y eficaz, por el Señor Jenaro González R., geólogo del instituto citado.

después a la América del Sur, dejando hacia el norte, dentro del territorio mexicano, una zona amplia de poca altura y con escaso relieve, que se continúa hacia el nordeste para formar la península de Yucatán.

La porción noroeste del país está formada por la península de la Baja California, la que fisiográficamente está constituida por un espinazo montañoso con dos vertientes—una hacia el Océano Pacífico y otra hacia el Golfo de California.

La porción septentrional de la gran altiplanicie mexicana forma una gran cuenca o enorme bolsón que comprende los desiertos típicos de Chihuahua, Coahuila, Durango y Zacatecas; la monotonía de las grandes llanuras que constituyen esos desiertos, se encuentra interrumpida por serranías aisladas generalmente de poca altura. La porción meridional de esa gran altiplanicie constituye lo que se llama propiamente "Mesa Central," dentro de la que están situados algunos hermosos y fértiles valles como los de Uruapan, Morelia, Toluca, México y Puebla. Al sur de estos valles y en la pendiente meridional de las sierras que limitan al sur la Mesa Central ya citada, se encuentran otros valles de clima cálido, como los de Iguala, Amacuzac, Jorullo y Apatzingan, hasta alcanzar el valle longitudinal del río Balsas, cuya cuenca hidrográfica es muy extensa y tributaria del Océano Pacífico. Hacia el este de la Mixteca Oaxaqueña, corre el río Papaloapan, que desemboca en el Golfo de México y tiene una cuenca hidrográfica de menor extensión.

En relación con los anteriores elementos fisiográficos, la geología superficial del país se distribuye como sigue: La Sierra Madre Occidental está constituida esencialmente por rocas efusivas terciarias y post-terciarias en los Estados de Chihuahua, Sonora, Durango, Nayarit, Jalisco, Zacatecas, Michoacán, México, Guerrero, y Oaxaca; conteniendo además varios núcleos de rocas intrusivas postcámbricas que aparecen en los límites de Chihuahua y Sinaloa, en Durango, Jalisco, Michoacán, Guerrero, Oaxaca y Chiapas, y dicha sierra incluye también algunas porciones de rocas metamórficas tales como gneises, esquistos, cuarcitas y otras metamórficas, de origen sedimentario, que aparecen cerca de la costa del Pacífico en los Estados de Durango, Sinaloa, Michoacán, Guerrero, Oaxaca y sur de Puebla.

Las rocas ígneas que constituyen esta Sierra Madre Occidental, están representadas por granitos, sienitas, monzonitas, dioritas, andesitas, dacitas, riolitas, basaltos, tobas y brechas volcánicas, que se encuentran también en la Sierra Madre del Sur. En algunas porciones de estas sierras se encuentran rocas sedimentarias pertenecientes a varias divisiones del Cretácico, especialmente en los Estados de Oaxaca, Guerrero y Michoacán y muy poco en los Estados de Sonora y Sinaloa.

La Sierra Madre Oriental está constituida en su mayor parte por rocas sedimentarias, tales como calizas, pizarras, areniscas y margas, del período cretácico principalmente, aunque dentro de ellas se encuentran también formaciones jurásicas y rocas intrusivas y efusivas de edad terciaria o post-terciaria.

La gran altiplanicie mexicana está cubierta principalmente en sus llanuras por formaciones del Cuaternario, pero en los elementos de relieve que forman eslabones de las Sierras Madres, se encuentran tanto rocas ígneas como sedimentarias.

En la zona costera del Golfo afloran rocas sedimentarias del Terciario y del Cuaternario, mientras que en la zona costera del Pacífico se encuentran rocas cuaternarias, en los Estados de Sonora y Sinaloa, y rocas metamórficas en los Estados meridionales.

En la zona ístmica, que comprende los Estados de Chiapas, Tabasco y parte de Campeche, Veracruz y Oaxaca, aparecen rocas intrusivas postcámbricas en la parte sur de Chiapas, y hacia el norte se encuentran rocas del Jurásico, Cretácico, Terciario y Cuaternario, hasta llegar a la costa del Golfo.

La península yucateca forma en conjunto una losa calcárea integrada por rocas terciarias.

Por último, el macizo central de la península de la Baja California está integrado por rocas metamórficas paleozoicas y rocas intrusivas postcámbricas, cubiertas en parte por formaciones cretácicas o bien por rocas efusivas terciarias, excepto cerca del paralelo 25°, donde aparecen algunas formaciones sedimentarias terciarias de escaso espesor. Esta península, de acuerdo con su morfología y su constitución geológica, aparece como un desprendimiento de la porción continental que actualmente está separado de ella por el Golfo de California, pero probablemente en épocas anteriores se unía a dicha porción continental, cerca del Cabo Corrientes.

De la breve descripción anterior se desprende que las formaciones correspondientes a los períodos de la era paleozoica son escasas, estando representados únicamente el Mississippiano y el Pennsylvaniano en la región sureste del Estado de Chiapas.

Las formaciones que corresponden a la era mesozoica se han encontrado en los siguientes lugares: Las cretácicas preferentemente en la parte oriental y meridional del país, constituyendo las elevadas montañas de la Sierra Madre Oriental; también existen en las sierras aisladas de la gran altiplanicie; en los importantes sistemas orográficos de Guerrero, Oaxaca y Chiapas y en algunas porciones aisladas de la Sierra Madre Occidental. Las jurásicas, aunque escasamente representadas, en Sonora, Zacatecas, San Luis Potosí, Hidalgo y Oaxaca.

Las rocas que hicieron su aparición durante el Cenozoico—tanto ígneas como sedimentarias—se encuentran ampliamente representadas. Las de origen sedimentario, formadas durante los períodos eoceno, oligoceno, mioceno y plioceno, constituyen la península yucateca y parte del noreste de Chiapas. Esas mismas formaciones, juntamente con las del Cuaternario, constituyen la gran planicie costera del Golfo de México y la costa norte del Golfo de California.

Las rocas ígneas terciarias y post-terciarias, tanto intrusivas como efusivas, representadas por dioritas, andesitas, riolitas y basaltos, abundan tanto en la Sierra Madre Occidental como en la del Sur, pero aparecen también dentro de las calizas cretácicas en la Sierra Madre Oriental, aunque de una manera aislada.

Los grandes movimientos orogénicos a que estuvo sujeta la corteza terrestre, a partir de la era cenozoica, especialmente a fines del Cretácico, dieron lugar a zonas de fracturamiento y afallamiento, que constituyeron líneas de menor resistencia orientadas generalmente de noroeste a sudeste y por las que pudieron salir enormes cantidades de rocas efusivas terciarias, las que a su vez fueron también fracturadas por nuevos movimientos tectónicos, dando lugar a fracturas dentro de ellas, especialmente en los macizos andesíticos, cuyas fracturas sirven para albergar muchos de los criaderos minerales que se hallan en la Sierra Madre Occidental, los que, según parece, tienen francas relaciones con las rocas intrusivas de naturaleza riolítica o andesítica.

Los mismos esfuerzos orogénicos a que antes nos referimos, produjeron en otras porciones del territorio mexicano, especialmente en la Sierra Madre Oriental, plegamientos de distinta forma y extensión, principalmente en las calizas y pizarras del Cretácico, dentro de las que se formaron posteriormente criaderos minerales de distinto tipo a los mencionados en párrafos anteriores, a favor de las fracturas, planos de estratificación o cavidades existentes en las rocas sedimentarias ya citadas, estando también estos criaderos en relación inmediata con rocas intrusivas terciarias.

De acuerdo con las relaciones genéticas bosquejadas en los últimos párrafos anteriores, los criaderos minerales en México—aunque se encuentran distribuidos en casi todas las entidades federativas, con excepción de Tabasco, Campeche, Yucatán y Quintana Roo—forman provincias metalogenéticas bastante bien caracterizadas, no sólo por la naturaleza del metal o metales que constituyen la fuente principal de explotación del criadero, sino por la morfología y génesis de los criaderos mismos. Así, por ejemplo, en la Sierra Madre Occidental, donde dominan las rocas ígneas terciarias ya mencionadas, se encuentran preferentemente dentro de ellas, criaderos auríferos, auro-argentíferos, argentíferos y cupríferos, que corresponden en su mayoría al tipo de verdaderas vetas o "true fissure veins," pudiendo citar entre ellas los criaderos encontrados en Altar, Sonora; Rosario, Sinaloa; Batopilas, Chihuahua; Guanaceví, Durango; Topia, Durango; Tamazula, Durango; Hostotipaquillo, Jalisco; etc.

Como dentro de la Sierra Madre Occidental existen también formaciones sedimentarias, constituidas por calizas o pizarras, dentro de estas rocas aparecen criaderos de contacto y aún de segregación magmática, los que contienen esencialmente cobre o fierro.

En cambio, en la Sierra Madre Oriental, donde dominan las rocas calizas, se hallan de preferencia criaderos plumbíferos, generalmente en forma de bolsas o chimeneas, llenando cavidades preexistentes o bien de tipo metasomático, estando a veces asociados con minerales de zinc y en ocasiones con minerales de antimonio y mercurio, pudiendo citar como ejemplos los de Sierra Mojada, Coahuila; Naica, Chihuahua; Santa Eulalia, Chihuahua; y Zimapán, Hidalgo. Dentro de esta misma Sierra Oriental se hallan criaderos de cobre y de fierro, que tienen el tipo de criaderos de contacto o de segregación magmática y están relacionados con rocas intrusivas, tales como los de Mazapil, Zacatecas; Encarnación, Hidalgo; y Las Vigas, Veracruz.

En el borde meridional de la Mesa Central, afloran pizarras que se encuentran muy metamorfizadas por movimientos, y en ellas se hallan vetas o mantos de forma lenticular o irregular, que contienen principalmente minerales argentíferos o auro-argentíferos, con alguna ley de plomo, pudiendo citar entre este tipo de criaderos los que existen en los distritos mineros siguientes: Zacatecas, Zacatecas; Guanajuato, Guanajuato; Noria de Los Angeles, Zacatecas; Pinos, Zacatecas; San Felipe, Guanajato; Pozos, Guanajuato; El Doctor, Querétaro; y en la porción meridional: El Oro, México; Tlalpujahua, Michoacán; Zacualpan, México; Sultepec, México; Taxco, Guerrero; y otros.

Dentro de las formaciones metamórficas constituidas por gneises, esquistos, o bien por rocas intrusivas postcámbricas que, como hemos dicho antes, se encuentran cerca de la costa del Pacífico y en la Baja California, se hallan criaderos auríferos en forma de vetas lenticulares de escasa extensión y profundidad.

Como podrá verse en la carta adjunta, los criaderos propiamente auríferos son relativamente escasos en el país, pues la mayor parte del oro se extrae de criaderos auro-argentíferos. Sin embargo, entre las principales zonas auríferas reconocidas hasta hoy, se pueden citar las siguientes: Sierras de San Pedro Mártir y Sierra Juárez en el Distrito Norte de la Baja California; municipalidad de Altar, Sonora; El Oro e Indé, en Durango; Cerro Colorado, Chihuahua; Guadalupe de los Reyes, Sinaloa; Rosario, Sinaloa; Arteaga, Michoacán; Placeres del Oro, Guerrero; Sierra Juárez, Oaxaca; Tehuantepec, Oaxaca; y Las Minas, Veracruz.

Los criaderos argentíferos o plumbo-argentíferos se hallan de preferencia en la Sierra Madre Occidental, pudiendo citarse como ejemplos los que se encuentran en Batopilas, Chihuahua; Guanaceví, Durango; San Dimas, Durango; Tayoltita, Sinaloa; Pánuco, Sinaloa; Hostotipaquillo, Jalisco; Tlalpujahua, Michoacán; El Oro, México; Pachuca, Hidalgo; Guanajuato, Guanajuato; y Natividad, Oaxaca.

Entre las zonas cupríferas más importantes se pueden citar las de El Boleo, Baja California; Cananea, Sonora; Mazapil, Zacatecas; Tepezalá, Aguascalientes; Inguarán, Michoacán; y Teziutlán, Puebla.

Las zonas plumbíferas de mayor importancia reconocidas hasta hoy, son las siguientes: Mapimí, Durango; Velardeña, Durango; Chalchihuites, Zacatecas; Naica, Chihuahua; y Santa Eulalia, Chihuahua.

Los criaderos más importantes de antimonio existen en las Sierras de Catorce y Charcas, San Luis Potosí, pero los hay también en Camotla, Guerrero; en Mixtepec y Juxtlahuaca, Oaxaca; en Zimapán, Hidalgo; y en el Distrito de Altar, Sonora, en un lugar llamado "Antimonio."

Los centros de producción de mercurio más importantes en la República Mexicana son los de Huitzuco, Guerrero; Guadalcázar y Moctezuma, San Luis Potosí; y El Doctor, Querétaro.

Las regiones de alguna importancia industrial en que existen criaderos exclusivamente manganesíferos conocidos hasta la fecha, son las de Mulegé, Baja California, y las de Sonora, en el ex-Distrito de Magdalena.

El molibdeno se ha explotado, aunque en corta escala, en los municipios de Nogales y Cumpas del Estado de Sonora.

Los criaderos de fierro que tienen mayor importancia industrial en el país son los de Cerro de Mercado, Durango; Mamey, Colima; Las Truchas, Michoacán; Zaniza, Oaxaca; Hércules, Coahuila; Golondrinas, Nuevo León; San José, Tamaulipas; Encarnación, Hidalgo; Xaloxtoc, Morelos; Tlaxiaco, Oaxaca; Chila, Puebla; y otros.

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Breve descripción geológica de los distritos cupríferos productores más importantes

En la mayor parte de las entidades de la República Mexicana, excepto en los Estados de Tabasco, Campeche y Yucatán, existen numerosos criaderos de naturaleza cuprífera, que se encuentran distribuidos esporádicamente en todo el país y que no siguen un orden aparente en cuanto a su distribución geográfica. (Véase lám. 21.) Sin embargo, esa distribución está de acuerdo con la naturaleza de las formaciones geológicas en cada lugar, siendo estas formaciones factores importantes en la morfología y génesis de estos criaderos.

La mayor parte de los principales criaderos cupríferos que en México se han explotado hasta hoy, han sido considerados como criaderos de contacto y su mineralización se encuentra unas veces en el contacto de rocas ígneas (dioritas, andesitas) con caliza o pizarras cretácicas; otras veces la mineralización principal se encuentra directamente en las rocas sedimentarias, y en ocasiones, los clavos principales aparecen dentro de las rocas ígneas descompuestas, que están cerca del contacto. Algunos de estos yacimientos de cobre se hallan asociados con criaderos de fierro—separados entre sí por tramos estériles—y afectan la forma de vetas o de cuerpos irregulares.

El relleno metalífero de estos criaderos de cobre está constituido generalmente por calcocita, calcopirita y bornita, acompañados por cuarzo y algunos minerales


ZONAS CUPRIFERAS
DE LA
REPUBLICA MEXICANA
ESCALA 1:10.000.000.
ESTADOS UNIDOS DEL NORTE
GOLFO DE MEXICO
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GUATEMALA
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ZACATECAS
S. LUIS
AGUASCALIENTES
TEPIC
GUADALAJARA
GUANAJUATO
QUERETARO
MORELIA
TOLUCA
MEXICO
CUERNAVACA
TLAXCALA
PUEBLA
JALAPA
CIUDAD BRAVOS
OAXACA
VILLAHERMOSA
S. CRISTOBAL
MERIDA
CAMPECHE
SIGNOS: Zona Cuprifera. • Criadero de Cobre. +++++++ Limite Internacional. .... Limite de Estado. ◦ Capital de Estado. ——— Ferrocarriles.

de metamorfismo tales como granates, wollastonita, tremolita y vesuvianita, pudiendo citar como ejemplos de estos criaderos los de Cananea, Sonora; Tatatila y Zomelahuacán, Veracruz; Pánuco, Coahuila; Sierra del Carrizal, Nuevo León; San José, Tamaulipas; y San Juan de los Llanos, Puebla.

Existe otro tipo de criaderos cupríferos, aunque de menor importancia que los anteriores, que aparecen en rocas ígneas, tales como granitos, dioritas, andesitas y riolitas. Estos criaderos contienen a veces leyes de oro, pudiendo citar como ejemplos, los siguientes: En Ajuchitlán, Guerrero, se encuentran dentro de las granulitas, vetas angostas con matriz cuarzosa, que contienen minerales oxidados, oro nativo, cerargirita, malaquita y crisocola, en la porción superior, y hacia la profundidad aparecen la calcocita, argentita y sulfuros complexos de plata. En Ameca, Jalisco; Ojocaliente, Zacatecas; y en el ex-Distrito de Mina, Guerrero, se encuentran yacimientos semejantes a los anotados antes.

En Tepezalá, Aguascalientes, y Agostadero, Nuevo León, se encuentran vetas que arman en rocas andesíticas, cuyo llenamiento está formado principalmente por bornita y calcopirita con cuarzo y granate, conteniendo en la zona de oxidación, carbonatos de cobre, óxidos de fierro y algo de crisocola.

En el Mineral del Carmen, Durango, se conocen criaderos de cobre en el contacto de riolitas y calizas cretácicas, cuya mineralización pasa a las riolitas mismas y está compuesta de calcocita y calcopirita, con carbonatos de cobre y crisocola en la zona de oxidación.

Por último, hay otro tipo de criaderos cupríferos, tales como los de El Boleo, en Baja California, y algunos otros en el Estado de Michoacán, que arman en formaciones sedimentarias del Mioceno o del Plioceno, representadas por capas de conglomerados y areniscas rojas.

Muchos de los criaderos cupríferos existentes en el país, son prácticamente desconocidos, pues no se tienen datos concretos respecto a su morfología, génesis, leyes de sus minerales, condiciones de explotabilidad, etc., por lo que solamente nos hemos limitado a indicar su localización en la carta general de la República, que se adjunta. Otros criaderos han sido insuficientemente explotados en distintas épocas, pero no han sido estudiados debidamente, por lo que los datos que de ellos se tienen son escasos y aun algunos dudosos. Y por último, los criaderos más conocidos de los que se ha extraído la mayor cantidad de cobre en el país, se encuentran en los siguientes Estados: Sonora, en primer lugar; después Baja California; Zacatecas en tercer lugar, y por último otros en el orden en que aparecen en el cuadro estadístico de producción por Estados.

Intentaremos a continuación hacer una breve reseña respecto a las principales zonas o distritos cupríferos conocidos hasta ahora:

La zona cuprífera del Estado de Sonora es probablemente la más importante del país, ya que en ella es donde se ha registrado la mayor producción de cobre desde hace algunos años hasta la fecha. Se encuentra situada al norte del Estado y se extiende desde la línea divisoria con los Estados Unidos, hasta unos 100 kilómetros al sur, y desde las inmediaciones de Nogales y Síbuta hacia el oriente, hasta unos 125 kilómetros. En este perímetro se hallan los distritos mineros de Terrenate, Rey del Cobre, Trinidad, Imuris, San Rafael, Janoverachi, Cumpas, Pilares de Teras, Nacozari, Cananea y Pilares de Nacozari, siendo estos dos últimos los más ricos de la zona, pues de ellos proviene la mayor parte del cobre que se ha producido en México en estos últimos años.

Cananea

El distrito minero de Cananea está situado en la parte norte del Estado de Sonora, a unos 40 kilómetros al sur de la frontera internacional con los Estados Unidos del Norte y a unos 60 kilómetros de Bisbee, Arizona.

Cananea ofrece una zona muy interesante para el estudio de los depósitos minerales en relación con actividades ígneas y de formaciones estructurales. La región ha sido el centro de una profunda diferenciación magmática, donde los grandes movimientos tectónicos con sus resultantes, fracturas y fallas, ejercieron una gran influencia en la génesis de los criaderos minerales.

La región revela una historia geológica bastante complicada: las formaciones más antiguas parecen haber sido cuarcitas y calizas, probablemente del Paleozoico, que descansaban sobre granito y que fueron atravesadas, rotas y parcialmente cubiertas por varias emisiones de rocas ígneas, algunas de ellas intrusivas y otras efusivas. De estas emisiones, las que mayor metamorfismo produjeron, fueron las de carácter diorítico o granodiorítico; mientras que los gabros y las diabasas, que corresponden a la fase final de la acción ígnea, ejercieron aparentemente poca acción metamórfica y no revelan conexión con los criaderos minerales; sobre las calizas y cuarcitas se encuentran tobas riolíticas y riolitas.

Las masas intrusivas de sienita que se observan, son posteriores a las rocas sedimentarias y probablemente posteriores a las tobas; tanto las calizas como las tobas, se encuentran atravesadas por intrusiones de rocas dioríticas. Además de las rocas intrusivas ya mencionadas, se han identificado como del mismo tipo, el granito porfirítico y la monzonita. Las intrusiones de granodiorita y aún de pórfido cuarcífero, produjeron fenómenos de metamorfismo de contacto y tienen relación con numerosos depósitos minerales de importancia, aunque estos están subordinados a los encontrados en las zonas sericíticas o silicificadas del pórfido diorítico. Estos criaderos ocupan una faja de unos 9 kilómetros de largo por 3 kilómetros de ancho aproximadamente y siguen paralelamente a la gran falla conocida con el nombre de "Elisa." En algunos casos—como sucede en la mina del Capote número 2—el cuerpo mineralizado tiene la forma de una chimenea que arma en roca caliza.

El llenamiento de estos criaderos de contacto está formado esencialmente por calcopirita, esfalerita, bornita, magnetita, hematita y galena en una matriz de granate, calcita, hornblenda, piroxena y otros silicatos. En general esos depósitos tienen enriquecimiento de calcocita solamente a poca profundidad. Los sulfuros tienen leyes de oro y plata. En la zona sericitizada los minerales son pirita, calcopirita, esfalerita, cerusita, caolín, cuarzo, etc., y los minerales de enriquecimiento son generalmente cobre nativo, cuprita, algo de calcocita, azurita, malaquita, crisocola, siderita, calcita, limonita, etc.

El depósito mineral ha provenido de las soluciones que acompañaron a los magmas y en la mineralización es posible distinguir dos períodos de depósito—uno en el que las soluciones conservaron la forma gaseosa y otro en que su temperatura había disminuido de tal manera que conservaron la forma líquida.

Durante el primer período se formaron los criaderos típicos de metamorfismo de contacto, tales como los que se observan en las minas de Elisa y Puertecitos, que aparecen dentro de la caliza granatizada. Los cuerpos mineralizados de la mina del Capote, que atraviesan tanto las rocas ígneas como las sedimentarias, contienen mineralización de la segunda clase. En la mina del Demócrata se encuentran minerales de ambos tipos. En todos estos casos se han desarrollado fenómenos característicos de metasomatismo. Los cuerpos mineralizados de la mina del Capote contienen esencialmente pirita y cuarzo, con algo de calcopirita y blenda.

Los criaderos que se explotan en la mina Enriqueta aparecen en el contacto entre la diorita y el pórfido cuarcífero y su mineralización es parecida a la de los cuerpos mineralizados que se explotan en las minas de Puertecitos y Elisa, con excepción de los minerales silicatados de cal. Los criaderos cupríferos que se explotan en la mina Duluth, tienen composición semejante a la de los mencionados últimamente y ocurren en una intrusión de pórfido diorítico que corta a las tobas, encontrándose los clavos más ricos a lo largo de la zona de brechas en la periferia de la intrusión, y la masa misma de esta intrusión se halla impregnada con cuarzo y pirita. En este tipo de criaderos se encuentra también tetraedrita y son algo más ricos en plata que los otros yacimientos de la región.

En las minas de Cobre Grande y Bonanza se encuentran también impregnaciones de pirita y cuarzo, en el contacto de las tobas y el pórfido diorítico.

El enriquecimiento secundario tiene importancia variable en los distintos tipos de criaderos que se han mencionado y las diferencias que se notan dependen más bien de causas físicas que químicas. Así, por ejemplo, en la mina del Capote, el enriquecimiento secundario ha desempeñado un papel muy importante para el mejoramiento de esos depósitos cupríferos, para lo que influyeron sin duda, entre otras causas, la permeabilidad en grande de las rocas fracturadas; la arcilla proveniente de la alteración de las rocas, que detuvo el cobre de las soluciones descendentes; y la gran masa de minerales primarios, que probablemente existieron en un principio y que después fueron desgastados por la erosión.

En los criaderos que arman en pórfidos, el enriquecimiento secundario no ha sido tan profundo como en el caso anteriormente citado, probablemente debido a la falta de mineralización abundante en la porción superior.

En los criaderos metamórficos de contacto que arman en caliza, el enriquecimiento secundario, abajo de la zona de oxidación, es de poca importancia, debiéndose esto, probablemente, a que la roca granatífera no se fracturó fácilmente.

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Pilares de Nacozari

La mina de Pilares se encuentra situada en el municipio de Pilares de Nacozari, Estado de Sonora, en la vertiente oeste de la Sierra Madre Occidental, dentro de una de las regiones más montañosas del Estado y a 1,425 metros sobre el nivel del mar.

En este distrito cuprífero se encuentran rocas sedimentarias e ígneas, que han sido fuertemente dislocadas con movimientos orogénicos, siendo las primeras las más antiguas que se conocen y están representadas por sedimentos silicificados, los que pueden observarse al sur de Nacozari. Sobre estos sedimentos descansa una serie de corrientes riolíticas, probablemente más recientes que las andesitas y conglomerados, descubiertos en la mina de El Porvenir. Después de haber estado sujetas a la erosión estas andesitas fueron cubiertas por corrientes de latitas, las que a su vez fueron casi totalmente removidas, por el mismo proceso, excepto en las partes altas de las montañas. Además de las rocas mencionadas, se observan diques de diabasa, posteriores al período mineralizador. Probablemente este período está relacionado con la intrusión del magma ácido, que dió origen a las latitas y riolitas.

El criadero de Pilares tiene la forma aproximada de un óvalo, de 600 metros en su eje mayor y unos 300 metros en su eje menor; el primero con rumbo N. 31° W. y el segundo con rumbo N. 57° E.

Las rocas han sido alteradas intensamente en algunos casos por las soluciones mineralizantes y el criadero mineral pertenece a los formados a profundidad moderada, por soluciones termominerales provenientes de un cuerpo intrusivo. Los minerales principales que constituyen el llenamiento son bornita, calcopirita y calcocita, con pirita en proporción notable; a veces se observa algo de blenda. Entre los minerales de enriquecimiento secundario se observan cobre nativo, cuprita, malaquita y azurita, con cuarzo y calcita como matrices. Esporádicamente se encuentra a veces la calcantita.

El enriquecimiento secundario ha desempeñado un papel importante en este criadero, quedando como vestigios de este proceso los "pilares" de óxidos de fierro, que forman parte de los "crestones."

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El Boleo

La zona cuprífera de Baja California se encuentra cerca de la porción central de la península, en una faja de terreno que abarca desde los alrededores de Mulegé hasta unos 50 kilómetros al noroeste; con cerca de 25 kilómetros de ancho en promedio. En esta porción de terreno se encuentran los distritos mineros de El Boleo y Mulegé, donde se explotan cuerpos mineralizados que tienen características muy semejantes y en los que predominan minerales cupríferos.

Las minas de esta zona se hallan en Santa Rosalía, casi a la latitud del puerto de Guaymas, Sonora. Los terrenos son típicamente áridos, con profundos cañones acantilados y con frecuencia se encuentran figuras de erosión labradas por el viento.

La columna estratigráfica del lugar incluye las siguientes formaciones: granodiorita plutónica, que sirve de base a una formación de cuarcita, apareciendo esta última en pequeños afloramientos de espesor desconocido; y tanto una como otra, son probablemente precretácicas. Sobre la cuarcita descansan corrientes de andesita y sobre esas corrientes aparecen las siguientes formaciones sedimentarias, que corresponden probablemente al Plioceno: capas yesíferas con un espesor probable de 100 metros; capa delgada de caliza dolomítica fosilífera; capa núm. 4, con minerales cupríferos conteniendo madera silicificada, con espesor probable de 10 metros; toba arenosa de 40 a 80 metros de espesor, seguida por conglomerado de 25 a 50 metros de espesor; capa mineralizada (núm. 3) de 1 a 3 metros de espesor, seguido de 20 a 45 metros de tobas y de 15 a 40 metros de conglomerados, constituyendo estos últimos la base de la capa mineralizada núm. 2, de poco espesor. Siguen capas de toba arenosa y conglomerado, de unos 50 metros de espesor cada formación y sobre ellas se encuentra la capa mineralizada núm. 1, cuyo espesor llega a ser hasta de 4 metros y es rica solamente en algunas partes. Sobre esta última se encuentran tobas con espesor de unos 35 metros; después la capa mineralizada núm. 0, cuyo espesor llega a ser hasta de 1.50 metros y que se halla removida casi totalmente por la erosión. En seguida se observan areniscas y tobas en un tramo de 4 a 20 metros; después conglomerados con espesor variable entre 40 y 100 metros y por último arenisca calcárea fosilífera, que alcanza hasta 15 metros.

Las formaciones pleistocénicas están representadas por capas de conglomerado dentro de las que se hallan intercaladas corrientes de basalto, y el espesor de estas formaciones varía entre 5 y 45 metros, estando cubiertas en algunas partes por aluviones recientes.

Los yacimientos de esta zona han sido considerados como "terciarios" y las capas mineralizadas están cortadas por un sin número de fallas del tipo normal. Su llenamiento consiste esencialmente de arcilla jabonosa negra, impregnada con óxidos de fierro y manganeso, y en este material se encuentran diseminados como minerales útiles la calcocita y algo de covelita; la calcocita es de grano fino, terrosa y contiene un 3 por ciento de carbón. El contenido de cobre de los mantos explotados números 1 y 3 es notablemente constante—$4\frac{1}{2}$ por ciento.

Además de los minerales anotados antes, se encuentran algo de cobre nativo, bornita, calcopirita y pirita en poca cantidad; los productos secundarios encontrados cerca de la zona de oxidación son cuprita, melaconita, malaquita, azurita, crisocola, atacamita y las especies minerales raras boleita y cumengita.

Los minerales explotados contienen pequeñas cantidades de cobalto, níquel, zinc, plata y plomo.

Estos criaderos cupríferos son difíciles de clasificar, ya que su origen es muy obscuro. Se han expuesto diversas teorías sobre su génesis: algunos los consideran como criaderos singenéticos; otros les atribuyen un origen hidro-termal; y finalmente hay otros que opinan que se deben a lixiviación de las tobas que se les sobreponen y las que deben haber tenido un porcentaje bajo de cobre, el que fué concentrado por la acción de aguas circulantes y depositado en las capas arcillosas inferiores, siendo el carbón vegetal que contienen, el agente reductor que ayudó a la precipitación del contenido mineral de las aguas descendentes.

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Concepción del Oro

La tercera zona cuprífera, que en orden de importancia puede citarse dentro del país, está situada al norte del Estado de Zacatecas, cerca del límite con el de Coahuila y comprende los distritos mineros de Concepción del Oro y Mazapil, que están a unos 10 kilómetros uno del otro.

El distrito minero de Concepción del Oro está ubicado en el extremo nordeste del Estado de Zacatecas, en terreno formado por montañas muy escarpadas y de fuertes pendientes. En él aparecen formaciones sedimentarias del Jurásico y del Cretácico, así como afloramientos de una intrusión ígnea que produjo intensos fenómenos de metamorfismo de contacto y que probablemente tiene estrecha relación con la génesis de los ricos criaderos cupríferos allí explotados.

Las rocas mesozoicas de esta zona estuvieron sujetas a fuerzas tectónicas que las dislocaron y produjeron en ellas plegamientos muy complicados. La caliza que aparece en los picachos de Abra y Los Angeles, contiene Nerineas y en algunos tramos aparece metamorfisada.

Según Burckhardt, el Jurásico y el Cretácico de esta área corresponden a dos regiones tectónicas diferentes en posición, separados por una falla. Durante el Mesozoico se formó un gran pliegue sinclinal en tal posición, que sus "alas" quedaron casi horizontales, como se puede ver en el Cerro de los Tajos; después, debido a la intrusión de la granodiorita, se elevaron los estratos del sinclinal.

De acuerdo con su situación y teniendo en cuenta los caracteres de la mineralización, en los diversos criaderos minerales que se explotan en esta zona, Bergeat los divide en dos grupos—los del este, que corresponden a los explotados en las minas de Cabrestante, Cata Arroyo, Promontorio, Las Animas y El Carmen; los del oeste, que corresponden al grupo de las minas de Aranzazú. En ambos grupos se encuentra la calcopirita acompañada por abundante granate. Tanto en la mina de Cabrestante como en la de Cata Arroyo, los criaderos minerales aparecen localizados en el contacto de la granodiorita con la caliza cretácica; en el grupo oriental, la mineralización se encuentra ligada a las masas de contacto y no parece estar relacionada con las grietas. Las cristalizaciones perfectas de pirita y magnetita abundan; pero tanto la galena como la esfalerita ocupan un lugar subordinado, por lo que se refiere a su abundancia; también se encuentra ortoclasa de origen secundario, anfibolita y zoisita.

En el grupo de Aranzazú, que es el más importante, los depósitos están en íntima relación con los agrietamientos que cruzan las calizas en sentido perpendicular a sus planos de estratificación, o bien, los depósitos adquieren la forma de bolsas o chimeneas. La pirita no es abundante, pero en cambio se encuentra bastante esfalerita y tetraedrita; estando la matriz constituida principalmente por cuarzo y wollastonita. Los minerales primarios son calcopirita, tetraedrita, calcocita y esfalerita, apareciendo la bornita como mineral secundario. En el grupo del este los minerales primarios son calcopirita con leyes de oro y plata, pirita, pirrotita, esfalerita, galena, magnetita y hematita micácea, y los secundarios son covelita, calcocita, cobre nativo, cuprita, azurita, malaquita, dolomita, siderita, cerusita, limonita, goethita, caolín, cuarzo y calcita.

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Michoacán

La zona cuprífera que se encuentra en el Estado de Michoacán es una de las más extensas del país, pues además de abarcar una gran porción territorial en dicho Estado, se prolonga hasta la parte occidental de los Estados de México y Guerrero. Sin embargo, los criaderos minerales que se encuentran en toda esta región, han contribuido poco a la producción de cobre del país, sin que se sepa con certeza si esto se debe a que dichos criaderos tienen poca importancia industrial, o bien porque no ha sido posible explotarlos con motivo de otras causas. En esta región se encuentran las zonas cupríferas de Coalcomán, Inguarán, Churumuco, Oropeo y Huetamo en el Estado de Michoacán; Balsas, Xochipala, Ajuchitlán y Pungarabato en el Estado de Guerrero.

Los criaderos cupríferos de Inguarán son conocidos en la localidad con el nombre de "güedales" y afloran en una porción extensa conteniendo cuarzo, calcita, óxidos de fierro, malaquita, cuprita, a veces cobre nativo; y hacia la profundidad aparecen calcopirita, bornita y calcocita, como minerales esenciales del llenamiento. Estos yacimientos han sido explotados en pequeña escala desde el tiempo de los primitivos pobladores, quienes fueron los indios tarascos, pero los labrados son poco profundos y actualmente están inaccesibles. Dichos criaderos no han sido estudiados convenientemente y por ello son desconocidas sus características genéticas y morfológicas.

La zona cuprífera comprendida entre Huetamo y Churumuco es bastante extensa y en ella se encuentran manifestaciones abundantes de minerales sulfurados de origen primario o secundario. Existen relaciones de trabajos antiguos diseminados en toda esta zona y aún hay datos respecto a la explotación de algunas pequeñas minas, donde se encontraron minerales con leyes altas de cobre. Sin embargo, estos criaderos minerales no están debidamente estudiados y no se disponen de datos recientes respecto a sus características principales.

Tanto en la zona de Inguarán como en la de Churumuco y Huetamo, se encuentran micrograņulitas cubiertas por rocas andesíticas y tobas.

Estas zonas cupríferas de Michoacán abastecieron en tiempos remotos las fundiciones que había establecidas en el pueblo de Santa Clara del Cobre, en donde se obtenía buena cantidad de este metal para la fabricación de utensilios domésticos.

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San José

Los criaderos cupríferos de la zona de San José, Tamaulipas, han sido considerados como metamórficos de contacto y se encuentran, según G. I. Finlay y J. F. Kemp, en una área de calizas cretácicas y de sienita con nefelina, apareciendo además una diorita porfídica como roca intrusiva. Tanto la caliza como la roca intrusiva se encuentran cruzadas por tinguaita y diques de gabro. Cerca de los contactos entre las calizas y las dioritas se encuentra una zona mineralizada con silicatos y minerales sulfurados de cobre, así como magnetita en grandes masas, de forma irregular, conteniendo venillas de calcopirita y pirita. El principal mineral de cobre es la calcopirita, que juntamente con la pirita, se presenta en venillas o formando costras. Los minerales cupríferos secundarios incluyen cuprita, azurita, malaquita y crisocola, que se encuentran en la zona de oxidación, especialmente siguiendo las fallas.

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Sierra de Magistral

La Sierra de Magistral en el Estado de Puebla se formó probablemente durante el Eoceno y en ella se encuentran las rocas siguientes: calizas, areniscas y pizarras, estando estas dos últimas metamorfizadas en la parte oriental. Hacia el oeste las calizas y las areniscas han sido notablemente metamorfizadas por una intrusión diorítica, que hizo probablemente su aparición al efectuarse el movimiento orogénico, produciendo fenómenos de metamorfismo de contacto en una gran área y mineralizando la caliza en varios lugares. La roca de contacto es granatífera (grosularita, almandita, etc.) y contiene además wollastonita acompañada de epidota, mica, pirita, pirrotita y calcopirita.

Algunos de los criaderos minerales se encuentran dentro de la roca de contacto y otros siguen aproximadamente la superficie de contacto a poca distancia de la caliza. En las minas del Magistral y La Paz, se encuentran cuerpos mineralizados del primer tipo; siendo notable en esta última mina una gran falla transversal al plano de contacto y un dique de pórfido gris, que parece tener relación estrecha con la falla y posiblemente con los cuerpos minerales que se presentan en forma de chimeneas. En la mina de Armando se encuentran criaderos del segundo tipo y allí los clavos mineralizados afectan la forma lenticular, mientras que en las minas de Valenciana y Lincoln, los clavos mineralizados tienen forma tabular. Los minerales primarios sulfurados de estos criaderos son calcopirita y pirita con granates y wollastonita, y entre los secundarios se observan limonita, cuprita, azurita, malaquita y crisocola. Dentro del mineral que se explota se encuentra algo de oro nativo.

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Otros yacimientos

En otros lugares del país existen yacimientos cupríferos que abarcan zonas relativamente pequeñas, pero que no obstante tienen algún interés industrial, debido a las leyes elevadas de los minerales que contienen. Tales son por ejemplo los criaderos de Asientos y Tepezalá en el Estado de Aguascalientes; los de Catorce, Cedral, Charcas, Matehuala, La Paz y Salinas en el Estado de San Luis Potosí; y los de Teziutlán en Puebla.

Merecen también interés, aunque no tienen la importancia que los anteriores, los criaderos cupríferos de Candela, Sierra Mojada y Viesca en el Estado de Coahuila; los que se encuentran situados en diversos lugares de los municipios de Aldama, Chihuahua e Hidalgo del Parral en el Estado de Chihuahua; los de Pozos en el de Guanajuato y los de Cuencamé y San Juan de Guadalupe en el Estado de Durango.

Los caracteres distintivos más notables referentes a los métodos de exploración, explotación y tecnología general de la producción

Cananea

Para dar una idea de los métodos de exploración que se han seguido en este distrito minero, cuya localización ya indicamos en otro lugar, transcribimos a continuación los siguientes párrafos tomados de una traducción de un artículo por Catron hecha por el ingeniero Salvador Peña, inspector del Departamento de Minas:

La exploración se efectuó al principio por medio de cueles de tiros o socavones sobre los crestones mineralizados o en la vecindad de rebosaderos de hierro notables, que se consideraban como indicaciones de enriquecimiento secundario a la profundidad. Después, continuando hasta la actualidad, se ha sondeado mucho el distrito. La exploración en nuevos campos se ha hecho con sondas rotatorias (churn drilling) desde la superficie; el sondeo por medio de barrenas de diamante se hace en el interior generalmente para explorar o para desarrollar yacimientos ya descubiertos.

Sondeo por percusión (churn drilling): Se hicieron muchos sondeos en la prolongación al suroeste de la falla Ricketts intentando encontrar la continuación lateral del yacimiento de Oversight. En las colinas de La Colorada y Sonora se practicaron sondeos según un plan sistemático, localizando las perforaciones en los puntos de intersección de una cuadrícula cuyas paralelas se trazaron a distancia de 61 metros. Al principio cuando principalmente se buscaban minerales secundarios, los sondeos sólo se llevaban a una profundidad que variaba entre 91 y 152 metros; pero al descubrirse la existencia de menas primarias ricas, los sondeos se proseguían hasta profundidades que alcanzaban de 240 a 480 metros.

Los sondeos no necesitaban entubarse, con excepción de unos cuantos dados en terreno blando, como en el área del Oversight. Los sondeos se muestreaban cada 5 pies a partir de la superficie, en toda su profundidad. Todo el detritus del sondeo se pasaba por un cortador de muestras que separaba la cuarta parte. Esta muestra, sin asentarla ni decantarla, se desecaba al fuego y se ensayaba por cobre. Se ensayaban muestras compuestas, representando 12 a 15 metros de longitud, por oro y plata. Un geólogo examinaba el detritus y tomaba nota de la clase de roca a través de la cual se barrenaba.

Sondeos de diamante: Anteriormente no se usaban los sondeos de diamante para el reconocimiento superficial. En la mina Elisa se practicaron algunos sondeos con el fin de determinar la naturaleza geológica de una área desconocida. En El Capote se practicaron, desde el nivel más profundo, perforaciones verticales e inclinadas, con objeto de investigar la extensión de las menas primarias. En la mina de La Colorada se reconoció un yacimiento de baja ley, por medio de sondeos horizontales dados en dos niveles, correspondiéndose con regularidad, en una cuadrícula vertical.

La corona usada en los sondeos de diamante, da un taladro de 38 milímetros y un núcleo de 20.6 milímetros. No se han entubado estos sondeos. En ocasiones, algunos sondeos se han impermeabilizado con cemento, a fin de prevenir la pérdida de agua. El detritus se hace pasar por un muestreador del tipo de canalillos, el cual corta una muestra de 1/8. La muestra se coloca en un secador o filtro de aire comprimido, el cual elimina la mayor parte de la humedad. Este filtro se adoptó después de haber probado charolas y canalones asentadores, que se pensó originaban error, ya sea durante la decantación o debido a la concentración de los minerales de cobre en las ranuras de los canalones. El filtro tiene la ventaja de ser fuerte y de pequeñas dimensiones; además, es de fácil y rápido manejo. Como no tiene capacidad para contener todo el detritus y el agua de la muestra que provienen de una porción dada del barreno, es a veces necesario eliminar dos o tres veces el agua, a fin de obtener una muestra completa. Se usa lona gruesa para filtro; el agua pasa prácticamente clara. Las muestras secas se pesan y se ensayan por cobre por el método del permanganato.

El núcleo no se quita a intervalos regulares, sino se saca cada vez que el portanúcleos está lleno o que se necesita sacar las varillas de la sonda por cualquier motivo. Cada sección del núcleo que se extrae, se considera como unidad. El porcentaje del núcleo recuperado se anota cada vez que se extrae alguno de sondeo. El núcleo se inspecciona cuidadosamente por un geólogo todos los días; se hacen las anotaciones necesarias para los archivos. Se toma un pedacito del núcleo como ejemplar permanente y el resto se envía a la oficina de ensaye, donde se muele, se pesa y se ensaya por cobre, por el método del permanganato. Si se desean ensayes por oro y plata, se pueden hacer de las muestras de todo el sondeo, de ciertas porciones de él, o de fracciones individuales del núcleo. Merecen más confianza, en lo que atañe a la mineralización del terreno atravesado, los ensayes de los núcleos; el detritus de ensaye de comprobación. Cuando se desea un valor combinado, se puede calcular de acuerdo con los pesos relativos del núcleo y del detritus o según los porcentajes de núcleo y detritus recuperados y los volúmenes correspondientes. El porcentaje del núcleo recuperado varía mucho en los distritos. En la mina La Colorada, se recuperaba del 40 al 95 por ciento del núcleo, siendo el promedio 75 por ciento; en la mina La Elisa, en caliza dura, se recuperaba más, en tanto que en terreno blando de El Capote, el por ciento recuperado era generalmente inferior a 50 por ciento.

Perforación de barrenos largos: Se han perforado muchos barrenos de reconocimiento en las minas La Elisa y La Colorada, valiéndose de una perforadora común del tipo pesado. Su principal aplicación ha sido para delimitar los cuerpos minerales, en lugar de colar cruceros para cortar las vetas y sirviendo de esta manera para proyectar el trabajo de desarrollo. Todos los barrenos han sido horizontales o de poca inclinación y han variado entre 11 y 38 metros de longitud, habiendo dado un promedio de 26.

La perforadora es análoga a la usada en la barrenación de cañones; pero está provista de una conexión rotatoria para la manguera del agua, dispuesta en la cabeza de la máquina. Antes de la conexión va un bloque de 38 milímetros, ajustado a la "trompa" de la máquina; en el extremo libre de la conexión rotatoria va atornillada la barrena, a cuya cabeza se le ha hecho rosca para ese objeto. El bloque se templa después de cada barreno. Siempre se debe disponer de agua de mina a suficiente presión para no bombear. La perforadora se monta en una barra transversal sostenida por dos columnas. Se usa acero redondo hueco de 32 milímetros de diámetro en longitudes de 1.80 metros; hay piezas de 1 metro que sirven para hacer los cambios. Las barras se empalman con uniones de manguillo. Los gavilanes se forjan en barras de 1 metro; la boca de la barrena "rompedora" es de 76 milímetros de diámetro y en las siguientes decrecen 1.6 milímetros sucesivamente. Todo el detritus del barreno se guarda, se deja asentar en charolas y se decanta el agua. Dos obreros se destinan para manejar la perforadora. En 64 puebles se barrenaron 12 barrenos, con un total de 350 metros, incluyendo en ese tiempo el requerido para mover la máquina y colocarla en sus diferentes emplazamientos; en la forma indicada, se obtuvo un promedio de 5.6 metros por pueble.

Los sondeos antes descritos, se han hecho de preferencia en los afloramientos ferruginosos, silicosos, caolinizados o sericitizados, que se encuentran preferentemente siguiendo: (1) Fracturas con rumbo noroeste entre cuarcita y caliza o bien en la diorita sericítica, que es característica en la mina Oversight; o a lo largo de fracturas que contienen fierro, como en la mina Capote; (2) zonas de diorita silicificada brechoide, como en la mina Duluth; (3) afloramientos irregulares de diorita silicificada, lejos de todo contacto, como en la mina de Veta Grande; (4) zonas de alteración; (5) grandes reemplazamientos ferruginosos irregulares en caliza; (6) contactos entre diorita y caliza.

De la traducción antes mencionada del ingeniero S. Peña, tomamos los siguientes párrafos:

Métodos de explotación (*rebajes*).[2]—La negociación de Cananea ha presentado ejemplos de casi todos los métodos de explotación conocidos, tanto en la época presente como en las pasadas.

En 1910, estaban en trabajo unas 8 o 10 minas y producían mineral por media docena de métodos distintos. En Puertecitos se explotaba un mineral de ley baja, en caliza granatífera y bancos a cielo abierto. El tumbe se hacía por barrenos de pulseta de 6.7 a 7.4 metros de largo, disparados con pólvora negra. Un gran porcentaje de material tumbado no se aprovechaba. La eficiencia del método era de 4,100 kilos de material arrancado por obrero y por pueble. Se usaba el sistema de cuadros, pero principalmente como auxiliar de otros métodos, obtenidos con él, a lo más el 5 por ciento de la producción total. El costo de este método es relativamente alto, variando de 1.32 a 1.55 dólares por tonelada, de mineral puesto en los chorreaderos, y solo por concepto de tumbes y madera. El sistema de cortes de cabeza con derrumbe ("top slicing") era el primero como productor de mineral. El método difería un poco del que se usa a la fecha; originaba un costo bajo por concepto de tumbe en el rebaje como de 0.76 a 0.77 dólar por tonelada, puesto en los chorreaderos. En determinadas condiciones se usaba un método combinado de derrumbe y almacenamiento ("shrinkage and caving system"), el cual consistía en un método de almacenamiento, con derrumbe de los pilares. Los rebajes se proseguían hasta llegar al terreno estéril o hasta el rebaje superior ya concluido; después de esto, los pilares se disgregaban por sí solos o se dinamitaban. No se usaba madera y con él se alcanzaron costos tan bajos que fluctuaban entre 0.44 y 0.55 dólar por tonelada. En el mineral duro de la mina La Elisa, se usa un método de corte y relleno; en este lugar los rebajes llegaron a alcanzar dimensiones de 23 por

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[2] Elsing, M. J., Mining methods employed at Cananea, Mexico: Eng. and Min. Jour., vol. 90, pp. 914, 963, 1910.

30 metros. El método difería del corte y relleno moderno, en que no se extendía planilla, porque era necesaria la pepena del mineral, pues cerca de 50 por ciento del material arrancado era tepetate. Para evitar la pérdida del material fino, el tumbe se hacía de manera de lograr pedruzcos grandes. Finalmente, en Veta Grande, se ejecutó lo que se llamó el "rebaje de pirámide." Este era una combinación del método de cuadros y del de almacenamiento ("square-set and shrinkage"). En el piso de donde arranca el rebaje, se delimitan bloques de 12 por 15 metros, por medio de cañones ademados con cuadros. A partir del cañón, se asienta con el rebaje por medio de una doble hilera de cuadros alderredor del bloque. El núcleo central de 9 por 12 [metros] se tumbaba por medio de rebaje de "shrinkage"; el exceso de mineral se sacaba por los chorreaderos dispuestos en los cuadros. El tepetate tenía por fuerza que tumbarse y sacarse del rebaje. Cuando todos los bloques de una sección determinada habían sido fragmentados, se extraía el mineral así quebrado. En el centro de cada rebaje se quedaba una pila cónica de mineral y de eso derivó el nombre de este método de explotación.

Estas pilas se sacaban colando un cañón por los centros de los bloques y después unos chiflones, hasta llegar al mineral de arriba. El costo del tumbe, por medio de este sistema, era de 88 a 99 centécimos de dólar por tonelada.

Actualmente se usan en La Colorada, Capote y Veta Grande, los sistemas de almacenamiento, corte y relleno (tanto horizontal como inclinado), rebajes de cuadros, corte de cabeza por derrumbe ("top slicing") y sistema de derrumbe con socave ("undercut caving"). Esta diversidad de sistemas se debe a la gran diversidad que existe en las condiciones de la roca encajonante y del mineral.

A veces el desarrollo o las explotaciones previas imponen los métodos futuros de trabajo y a otras, la necesidad de atender a la seguridad de los tiros o a las instalaciones de la superficie, son factores que deciden la adopción de los sistemas de explotación.

Costos parciales en los rebajes, mina La Colorada, agosto y septiembre de 1929

	Sistema de cuadros	Corte y relleno horizontales	Corte y relleno inclinados
Agosto			
Producción en el mes .... toneladas	8,485	14,131	7,746
Mano de obra.................dólares ..	0.6725	0.5322	0.5976
Explosivos......................do....	.0866	.1161	.1861
Madera..........................do....	.7888	.2482	.2361
Costos parciales...........do....	1.5479	.8965	1.0198
Septiembre			
Producción en el mes .... toneladas ..	8,147	16,768	7,961
Mano de obra.................dólares ..	0.5877	0.5672	0.4940
Explosivos......................do....	.0761	.1721	.1223
Madera..........................do....	.5992	.3074	.3868
Costos parciales...........do....	1.2630	1.0467	1.0031

Se extraen también grandes cantidades de cobre por el proceso de lixiviación y precipitación, usando tanques tanto en el interior de la mina como en el exterior. El proceso consiste esencialmente en precipitar el cobre contenido en solución, en las aguas de lixiviación, por medio del fierro, empleando corrientes de aire como agitadores a fin de mantener limpio el fierro y evitar que el cobre al precipitarse lo cubra. Además, así se ha logrado obtener un producto de alta calidad.

En Cananea, gracias a los métodos de explotación y equipo completamente moderno, se han reducido los costos de producción notablemente.

De las tres minas que se trabajaban en 1932—La Colorada, Capote y Veta Grande—se extraían cerca de 2,268 toneladas métricas por día, trabajándose en dos puebles de 8 horas cada uno.

Desde que la compañía actual comenzó a trabajar las minas de Cananea en 1901, hasta fines de 1928, se habían extraído un total de 18,197,794 toneladas métricas de mineral, peso húmedo; con una producción metálica de 468,182,060 kilos de cobre, 707,735 kilos de plata y 4,488 kilos de oro.

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Pilares de Nacozari

La compañía minera que explota los criaderos de la zona de Pilares de Nacozari forma una de las grandes unidades cupríferas del país, y hace sus exploraciones siguiendo los mismos métodos de sondeos que hemos descrito en el caso de Cananea.

De esta zona cuprífera se extrae más del 30 por ciento del cobre de México; y entre las dos negociaciones de Cananea y de Pilares, producen casi la totalidad del cobre del Estado de Sonora, cuya producción representa más del 50 por ciento de la total del país.

En sus trabajos de explotación, la compañía sigue los tres sistemas siguientes: el de rebaje de cabeza y relleno ascendente ("cut and fill"), el de rebaje descendente por secciones horizontales con relleno ("top slicing"), y el tercer método es aquel en que no se rellena el hueco que deja el tumbe de mineral, sino que a medida que se va disfrutando el macizo, se recibe al alto con huacales de madera, que van formando pilares.

Aquí como en Cananea, se dispone también de una pequeña planta de precipitación para el cobre.

Es digna de mencionarse la activa campaña que esta negociación hace en todos los departamentos de sus minas y plantas en pro de la seguridad, con objeto de reducir los accidentes al mínimum, habiendo ocupado el primer lugar en el Concurso de Seguridad organizado por la Compañía Phelps Dodge en sus cuatro centros mineros—tres en los Estados Unidos del Norte y Pilares en México.

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El Boleo

De acuerdo con la naturaleza de los criaderos minerales que se explotan en la región de El Boleo, Baja California, y que hemos descrito con anterioridad, los procedimientos que se siguen en ella para la exploración y explotación, difieren de los que hemos mencionado en los casos de Cananea y Pilares, Sonora.

Para dar una idea de los métodos seguidos por la Compañía de El Boleo, transcribimos a continuación los siguientes párrafos, tomados de un artículo del Señor Ing. Salvador Peña[3]:

La exploración en busca de más mineral, se ha hecho por medio de cañones y chiflones. Se llama "chiflón" localmente a toda galería que lleva o va con el echado del manto. Dadas las condiciones del criadero y su poca profundidad, la exploración por sondeos es la más indicada, solamente que por mucho tiempo se pensó que por la naturaleza deleznable del material de los mantos, sería cosa fácil que un sondeo atravesara un manto sin revelar la presencia del mineral; a la fecha en todos los sondeos se observan precauciones especiales cuando en el curso de un sondeo se sospecha o estima la proximidad de uno o cualquiera de los mantos.

La adición más importante de mineral, descubierta por medio de sondeos, es el área de San Luciano . . .

[El área de San Luciano está al sur del Boleo, y en ella está localizado el manto número 1, en una extensión como de 1,330 metros de largo por 250 metros de ancho, estimándose que allí se obtendrá como medio millón de toneladas de mineral con 4.5 por ciento de cobre. Los sondeos de exploración generalmente se hacen a 200 metros de distancia, reduciéndose ésta 100 metros cuando los mantos están cercanos, con objeto de determinar con más precisión los límites de la capa mineralizada. Cuando en las exploraciones se llega a las formaciones que contienen yeso o roca andesítica, las posibilidades de encontrar capas mineralizadas se consideran inútiles.]

Preparación de los rebajes o "tallas."—A partir de uno de los cañones del bajo, que como se ha dicho, van colados en el conglomerado y son firmes, se han dado cruceritos hasta cortar el manto; esos cruceros van espaciados de 100 a 120 metros. A partir de esos cruceros se cuelan los chiflones; los chiflones van siguiendo el manto de mineral, según su echado. Así como los chiflones han alcanzado una longitud de 100 a 180 metros, se comunican entre sí por una obra horizontal alojada en el manto; esta obra o cañón, se deja perder y no tiene más objeto que reconocer el bloque; su conservación resultaría muy costosa por ir alojada en el manto. Los chiflones son paralelos entre sí y van a distancia uno de otro de 100 a 120 metros, a no ser que los accidentes del manto (fallas) impongan sus condiciones.

Una vez delimitados varios bloques de mineral, se cuela, en lo que corresponde a su borde inferior: un contra-cañón o "nivel de rulage," el cual va alojado en el conglomerado del bajo. No hay equidistancia standard de nivel a nivel, sino que es muy variable, pues lo que se busca es delimitar los bloques lo más largo que se pueda en el sentido del echado, y llegar, si el manto no tiene irregularidades, al límite de 180 metros. De esta suerte la distancia vertical de nivel a nivel depende del echado del manto y de las irregularidades que éste presente.

Explotación.—En todos los casos en que el manto se presenta irregular, se adopta el sistema de tallas mecánicas; cuando el manto es irregular y no es provechoso usar el primer sistema, se dice que la talla es no-mecánica. Lo de "mecánico" se refiere exclusivamente al sistema de transporte en el rebaje o talla. Los rebajes o tallas mecánicas tienen un sistema de bandas transportadoras que en seguida se describirá.

De un total de 25,916 toneladas de mineral, producidas en el mes de marzo del presente año (1931), 23,376 provinieron de las tallas mecánicas, lo que da un porcentaje de 90 por ciento. El porcentaje por minas, es el que se da a continuación:

	Por ciento
Montado	63
Ranchería	98
Margarita	100
Santa Rita	89

[3] Véase Bibliografía, p. 401.

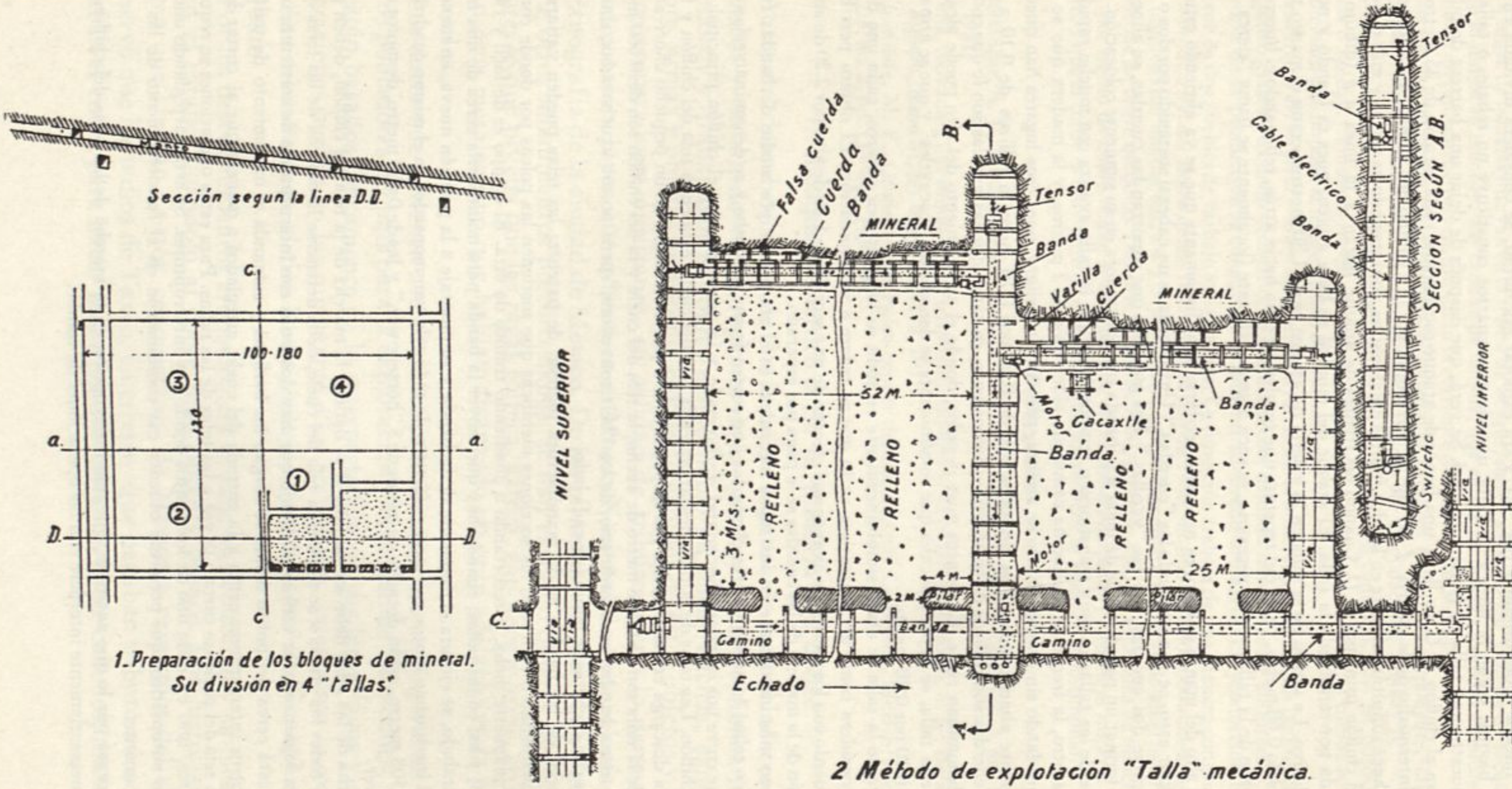

Figura 42.—Método de explotación de la mina de la Compañía del Boleo, Baja California. (Del Bol. minero, tomo 31, no. 6.)

Delimitado un bloque de la manera que se ha dicho, se explota primero la mitad que queda de un lado de la línea *a–a* del dibujo 1 (fig. 42). Para explotar esa mitad, se considera dividida en dos cuartos de bloque, según la línea *c–c;* cada uno de esos cuartos constituye un rebaje, o talla. El dibujo 2 muestra una talla en plena actividad. Se verá, que después de dejar una barrera de pilares que protejan al chiflón *D–C,* se lleva una frente de ataque escalonada, cada escalón de 25 metros de largo, con intermedio de la galería *A–B,* que es horizontal, por ir a rumbo del manto. El ataque del mineral se hace simultáneamente en las dos frentes escalonadas, conservándolas rectas y más o menos paralelas al chiflón principal *C–D.* Cuando las frentes de ataque llegan a la línea *a–b* (dibujo anterior), se da por terminada la talla. El ataque del mineral se hace a pico, pues es blando y no requiere explosivo. La altura de la talla en la galería de ataque es de 1.80 metros; como el manto tiene en general solo 0.60 metro, parte del tepetate que resulta, se echa hacia atrás, rellenando el hueco que deja el avance de la talla, y si es necesario, se saca algo de tepetate (localmente se llama "tierra"), al exterior.

Como el alto del manto es flojo, es necesario recibirlo inmediatamente que se va abriendo espacio; ya para lograr esto, se van armando las "cuerdas." Una cuerda es un cabezal sostenido por dos o más puntales; entre dos cuerdas van las "varillas." Los puntales que soportan las cuerdas, se alinean a manera de formar un pasadizo que dé lugar a la banda transportadora en su siguiente colocación.

El ademe de las tallas es muy transitorio o temporal, porque la talla avanza con mucha rapidez y de un día a otro, la frente de ataque ha caminado alderredor de 2 metros, y la madera que se deja atrás, va quedando sin objeto; el alto se asienta, pero ya sin peligro, pues esos lugares han quedado definitivamente abandonados. Los puntales son de 0.10 por 0.10 metro o rollizos de 0.10 a 0.15 metro; las cuerdas son rollizos de las mismas dimensiones, en tanto que las varillas son lo que comúnmente se denominan rajas. En puntos muy pesados, donde el asentamiento del alto puede alcanzar el frente de la talla, se dejan huacales que comúnmente se denominan "cacaxtles" y que se arman de madera de 0.10 por 0.10 metro.

La frente de la talla se ataca simultáneamente en toda su longitud por obreros, cada uno de los cuales se considera como un contratista en lo que se refiere a su liquidación. El obrero percibe su paga de acuerdo con los metros de avance que efectúa de una sección de 1.80 de alto por 2.20 de ancho; la colocación de la madera de las cuerdas se le paga por separado.

El proceso más importante en las tallas mecánicas es el transporte por medio de bandas transportadoras o telas; éstas son de tres clases, las que corren frente al tumbe y se denominan telas de la talla, la que corre por la galería horizontal *A–B* o cuele, y la que corre por el chiflón principal *C–D* o tela del chiflón. Las telas de la talla descargan en la tela del cuele, ésta en la tela del chiflón y finalmente, ésta descarga en las berlinas sea directamente o por intermedio de un pequeño chorreadero. Las telas de la talla son de 0.508 metro de ancho, la tela del cuele y la del chiflón son de 0.660 metro. El tipo de estas bandas es el ordinario, de los "belt conveyors," pero no son acucharadas, sino corren planas con cachetes de lámina de cada lado.

El material de las bandas es de manufactura inglesa, de patente; las telas pueden variarse de longitud, añadiendo o retirando las secciones metálicas que sostienen las poleas por donde corre la banda, propiamente dicha, y recortando o añadiendo tramos de ésta. El equipo es de fácil y rápida instalación; y así en las tallas, cuando hay que mover la banda para mantenerla cerca de una nueva frente de trabajo, se ejecuta el desmonte de la banda y su montaje a la posición nueva, en menos de 2 horas. El mecanismo motor y el motor eléctrico de cada tela van montados en el mismo cuadro. Las telas de 0.508 metro, están dotadas de motor de 8 "horsepower," y las de 0.660 metro, de motor de 10 "horsepower."

La marcha de las telas debe ser tal, que si se detiene la marcha de la tela del chiflón, deben parar su marcha todas las otras; si se detiene la tela del cuele, debe detenerse la marcha de las telas de las tallas. Para lograr esto, se verá en el dibujo que hay dos sitios con interruptores de corriente; un interruptor está cerca del punto donde se cargan las berlinas y comanda el movimiento de todas las telas; los otros interruptores están a la entrada del cuele, arreglados a manera que al cortar la corriente a la tela del cuele, se corta a la vez a las telas de las tallas. Para estas operaciones se requieren dos hombres, uno en cada uno de los puntos donde hay interruptores. Se están arreglando unos interruptores automáticos que permiten obtener esa coordinación en el funcionamiento de las telas, automáticamente.

Se observará por lo que antecede, que una interrupción en la marcha de las telas del chiflón, o la del cuele, necesariamente interfiere con las operaciones de tumbe.

El sistema de las tallas mecánicas, que se acaba de describir, se ha usado desde unos cuantos años y ha resultado de él un ahorro considerable en el costo por tonelada.

En lugar de las telas que van en la frente de ataque, suelen substituirse "canales de sacudida"; éstas, como lo indica su nombre, son canales de lámina, que en virtud de las sacudidas rítmicas que les imprime un mecanismo de vaivén, impulsan la corriente de metal en un sentido.

Cuando las tallas son no-mecánicas, el mineral se carga en berlinas directamente, las cuales son empujadas por dos hombres, o en caso necesario, jaladas por un malacate ("donkey").

En algunos casos, el mineral se encuentra no en un manto continuo, sino en porciones discontinuas o boleos, y entonces no es posible usar un sistema para explotarlo, y el tumbe se hace en las condiciones que impone la irregularidad del yacimiento.

Producción del mineral.—Para los fines de la fundición el mineral producido por las minas, se clasifica en cuatro clases—oxidado ordinario, oxidado silicoso, oxidado manganoso y sulfurado. . . . La gran mayoría de la producción la constituye el mineral sulfurado ordinario. La producción del Boleo se obtiene en dos puebles de trabajo en las minas. La fundición trabaja de una manera continua.

La producción del Boleo desde 1885 hasta el año de 1930, ha sido de 9,600,000 toneladas de mineral con una ley que fluctúa entre 4 y 5 por ciento, lo que representa un total de alderredor de 432,000 toneladas de cobre metálico. Durante el año de 1930, produjo 336,000 toneladas de mineral de ley de 4.31 por ciento de cobre. Cabe aquí decir que el contenido de plata y oro en el mineral es insignificante, y que el cobre es muy puro en el sentido que no contiene ni arsénico ni antimonio.

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Bosquejo histórico de la minería del cobre

Antes del descubrimiento de América, ya algunos de los pobladores (aztecas, tarascos y otros), de varias regiones de lo que hoy es la República Mexicana, conocían y trabajaban el cobre, empleándolo en hacer hachas, campanas de cobre, armas y objetos de adorno, enviando algunos de estos objetos y utensilios a los emperadores mexicanos, en calidad de tributo, como lo demuestran los documentos y joyas que existen en el Museo Nacional de Arqueología, Historia y Etnografía de la ciudad de México. De las pirámides de San Juan Teotihuacán y de otros monumentos precortesianos, se han extraído objetos de oro, plata y cobre, lo que prueba que las razas tolteca, azteca, zapoteca y otras, no solo conocían esos metales sino que habían alcanzado un gran adelanto en la manera de labrarlos.

Los datos que se tienen acerca de los procedimientos que empleaban los primitivos pobladores del país para la explotación y beneficio de los metales, son vagos y están basados únicamente en la interpretación de sus jeroglíficos y en las observaciones hechas en las minas que ellos trabajaron, tales como la explotación de una mina cercana al tiro Kurtz, sobre la veta madre en Guanajuato, Guanajuato.

Por los descubrimientos arqueológicos se sabe que conocían y empleaban también el estaño, ligándolo al cobre para obtener bronce. Los historiadores nos dicen que Hernán Cortés, conquistador de México a principios del siglo XVI, observó que los indios de Taxco, Guerrero—que pagaban tributo a los aztecas—usaban el cobre para hacer monedas. Necesitando hacer cañones, mandó buscar los yacimientos de cobre así como los de estaño y en el año de 1522, como resultado de esa búsqueda, se empezó el "Socavón del Río," cerca de Tehuilotepec, ex-distrito de Taxco, Guerrero, siendo la primera mina de América abierta por europeos.

En 1598 se principió la explotación de los criaderos de Mapimí, Durango, por oro, plata y cobre. En 1763 se descubrieron los criaderos cupro-auríferos de Zomelahuacán, Veracruz; y en 1828 los de Cuchillo Parado, en el ex-distrito de Iturbide, Estado de Chihuahua. En 1862 se inicia el descubrimiento de los grandes criaderos cupríferos mexicanos que en la actualidad producen casi la totalidad del cobre de México y que se encuentran en el Estado de Sonora. Respecto a Cananea, Sonora, el ingeniero Salvador Peña dice en su traducción (p. 13):

Historia.[4]—Poco se conoce acerca de los trabajos primitivos ejecutados por los españoles. Francisco Velasco, al escribir sobre Sonora por el año de 1845, afirma que las minas fueron trabajadas antes del siglo XVIII, por la casa de Guea y después por José Pérez, vecino de Arizpe, capital del distrito. Se dice, finalmente, que en el año 1865, el general Ignacio Pesqueira, con 500 soldados, estableció un campamento en Ronquillo, lugar donde se encuentra la fundición actual, y erigió una plantita de fundición en el lugar actualmente conocido como Cananea la Vieja. Las operaciones mineras se condujeron de una manera muy irregular, por espacio de 15 años. En 1881 una compañía de Cleveland construyó una fundición, al pie de las montañas, a 16 kilómetros al oeste de las minas de Cajoncito. Se fundía mineral que promediaba 20 por ciento de cobre y 460 gramos de plata por tonelada, llevándose las operaciones a cabo por espacio de 2 años. Se transladó la fundición a Puertecitos, pero se abandonó al año siguiente.

Las propiedades circunvecinas del Cobre Grande, se dieron en opción a Charles Benham, de Nueva York, hasta el año de 1886 y después a Major Morton, quien trabajaba por los intereses de F. Augustus Heinze. Después de sacar $110,000 en matas de cobre, esta opción se dejó perder, debido a la muerte de Major Morton.

Después de esto, el coronel W. C. Greene se aseguró el dominio de casi la totalidad de las propiedades mineras del distrito de Cananea; fracasando en su intento de obtener capital privado para desarrollarlas, organizó The Cananea Consolidated Copper Co., corporación mexicana; después puso en circulación las acciones de The Greene Consolidated Copper Co., la compañía poseedora, en el mercado de acciones de Nueva York. Esta compañía poco después se fusionó con The Greene Cananea Copper Co.

El primer horno de fundición empezó a funcionar en 1899; la primera concentradora se construyó en 1901, y el ferrocarril de vía angosta, que liga la planta con las diferentes minas del distrito, se concluyó en 1902.

En el año de 1900 se descubrieron el gran yacimiento del Capote y el del Oversight. Los depósitos de Chivatera y Veta Grande, existentes también dentro de la cuenca del Capote, se encontraron en fechas posteriores, así como numerosas minas de las más lejanas, tales como las de Cananea-Duluth, The American, Kirk, Cobre Grande, Sierra de Cobre, Elisa, Henrietta y Puertecitos. En 1926 se descubrió el yacimiento de La Colorada.

En lo que se refiere a El Boleo, Baja California, el mismo ingeniero Salvador Peña en el artículo ya citado (p. 162), dice:

Reseña histórica.—Los notables yacimientos de El Boleo, fueron descubiertos en 1862 por el ranchero José Rosas Villavicencio, cuando trataba de encontrar un paso fácil del interior al puerto de Santa Agueda. El notó en uno de los varios cañones, que corren normalmente a la costa, bolitas de mineral de vivos colores, verde y azul, de las cuales tomó varias y envió a diversas personas de Guaymas. En 1872, de esas personas algunas fueron a la región y dieron principio al laboreo de minas,

[4] Emmons, S. F., Cananea mining district, Sonora, Mexico: Econ. Geology, vol. 5, no. 4, pp. 312–356, 1910.

sobre los yacimientos descubiertos por Villavicencio, en una forma muy rudimentaria. Los obreros eran indios yaquis, de Sonora, quienes extraían el mineral en sacos de cuero crudo y se alumbraban con mechas de aceite. Los labrados de las minas eran irregulares, estrechos y pésimamente ventilados. Los yaquis ganaban 0.80 dólar y se les daba, además, la provisión de boca. El metal extraído fluctuaba entre 12 y 25 por ciento de cobre.

Los primeros pueblos mineros estuvieron en los arroyos o cañones de El Purgatorio y El Infierno. El agua era muy escasa, se extraía de algunas norias. El mineral se transportaba a Swansea, Inglaterra.

La ausencia de habitantes, la falta de recursos naturales y hasta el agua misma, hacía la explotación muy dificultosa. Cuando fue extraído el mineral rico, que no ofrecía obras muy costosas para su explotación, esto fué después de 10 años, el campo minero de Santa Agueda vió paralizar sus actividades (1884–85). Convencidos los pequeños explotadores que solo una empresa fuerte que pudiera afrontar los gastos que exigía lo inhospitalario del lugar y su carencia de medios, podía trabajar los yacimientos, se agruparon todos para formar una sociedad que ofrecería las propiedades del conjunto a una compañía fuerte. Los propietarios formaron, entonces, dos compañías—Elhuyar y Sontag—a la cabeza de las cuales estaban los señores Eustaquio Valle y Guillermo Eisenmann, respectivamente.

La Compañía del Boleo ha operado las minas desde el año de 1885 hasta nuestros días, de una manera continua y ha tenido que crear una población completa en Santa Rosalía con toda clase de servicios, así como construir un puerto, abrir caminos, etc.; de hecho la mina exclusivamente da vida a la región, y en caso de paralizar ésta, significaría la muerte de dicha región.

Desde la fecha en que comenzó a operar la compañía, ha extraído una cantidad de mineral que contenía alderredor de 432,000 toneladas de cobre metálico. La raya mensual de El Boleo es como de $250,000.

Años después del descubrimiento de los distritos cupríferos antes mencionados, se localizaron otras zonas cupríferas dentro del territorio mexicano, tales como las de Santa Fe, en el Estado de Chiapas, y otras que se han mencionado ya en capítulos anteriores.

En el año de 1900, una vez que la Greene Consolidated Copper Co. hubo instalado la maquinaria para las seis minas que entonces explotaba y una planta de beneficio con capacidad para 1,000 toneladas diarias, se inció la explotación activa de los criaderos cupríferos, logrando alcanzar México en poco tiempo, el segundo lugar como país productor de cobre, durante un período de 8 años, comprendido entre 1904 y 1912. (En 1908 España y Portugal unidos, ocuparon el segundo lugar.)

Tanto la Greene Consolidated Copper Co. como la Compagnie du Boléo y la Casa Guggenheim, comprendiendo la importancia de los criaderos de cobre mexicanos, invirtieron fuertes sumas en la explotación de las minas y la construcción de grandes plantas metalúrgicas, las que se han mejorado y modernizado con todos los adelantos de que en la actualidad dispone la industria minerometalúrgica.

Como se puede observar en el cuadro correspondiente a la producción general del cobre en México, durante los años de 1900 a 1931, se notan dos épocas de depresión—de 1914 a 1916 la primera, en que la producción descendió a menos de la mitad de la normal (año de 1915), debido a los trastornos de orden políticosocial. En 1918, a consecuencia de las necesidades creadas por la guerra europea y habiendo alcanzado el cobre un precio bastante alto que estimuló la producción, ésta se elevó a 70,000 toneladas. Es de gran importancia el hecho de que en 1921, después de descender el precio del cobre hasta 12.5 centavos de dólar la libra, las compañías que operaban en la República, se vieron forzadas a disminuir sus explotaciones al mínimum, lo que produjo la segunda época crítica para la minería del cobre en México, pues la producción decayó de 48,000 toneladas en 1920 a 15,230 en 1921.

El Boletín minero, ya citado anteriormente, en el número 3 del tomo 23, dice en su sección editorial:

Comparado el estado de la industria del cobre en el período de 1921 a 1926, en que el precio fué de 13.5 [de dólar] la libra, con el período de 1908 a 1913, en que fué de 13.8 (antes y después de la guerra mundial), se observa que no obstante que los minerales son de más baja ley que los tratados anteriormente, que los fletes, materiales consumidos, salarios, impuestos son muy superiores a los del período de 1908 a 1913, y que el precio se mantiene sensiblemente inferior, la producción ha ido en aumento progresivo.

Esto demuestra el grado de adelanto que se ha alcanzado en la industria del cobre, la que debe su desarrollo a las competentes direcciones técnicas e implantación sistemática de los procedimientos más modernos de explotación y beneficio, que les han permitido ponerse en condiciones de reducir sus costos y obtener beneficios.

La baja del precio del cobre ha tenido, por consecuencia el aumento del consumo en la industria y preparar el mercado para absorción de una mayor producción futura.

La producción en 1929 fué de 86,553 toneladas, la mayor que ha sido alcanzada por México como productor de cobre; en el siguiente año fué de 73,412 toneladas, descendiendo en 1931 a 54,211 toneladas.

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Datos estadísticos en minas trabajadas principalmente por cobre

Producción de cobre en México por Estados, en kilogramos, 1922–31[a]

Estado	1922	1923	1924	1925	1926	1927
Sonora	11,848,080	33,191,500	28,302,216	31,357,808	29,790,348	29,365,032
Baja California	6,550,000	7,352,779	7,865,000	7,550,000	10,110,000	10,475,000
Zacatecas	4,452,099	5,400,291	4,774,738	5,565,612	4,871,145	6,367,119
Chihuahua	230,557	188,884	2,226,597	2,909,853	3,612,102	4,671,927
San Luis Potosí	2,657,811	1,886,205	3,949,181	3,525,626	3,767,070	4,796,949
Puebla	....	....	....	345,890	1,792,333	1,680,738
Aguascalientes	655,970	728,087	382,904	465,373	248,070	594,520
Coahuila	370,280	399,238	256,047	628,014	511,303	1,100,430
Durango	....	1,223,231	1,972,758	1,954,510	1,231,473	395,451
Michoacán	....	....	133,705	85,281	28,950	35,123
Guanajuato	152,175	....	133,855	154,443	33,953	47,888
Nuevo León	....	....	55,034	14,135	17,928	3,493
Otros Estados	60,814	3,001,637	1,784,975	39,615	506,748	341,187
	26,977,786	53,371,852	51,837,010	54,596,160	56,521,423	59,874,857

Estado	1928	1929	1930	1931	Sumas
Sonora	34,388,833	45,838,017	33,984,996	28,199,162	306,265,992
Baja California	11,600,000	11,705,000	12,600,000	11,560,000	97,367,779
Zacatecas	7,610,904	7,374,060	7,203,297	2,378,626	55,997,891
Chihuahua	5,599,380	6,865,838	6,724,876	6,448,796	39,478,810
San Luis Potosí	4,635,447	4,365,498	4,819,568	1,091,190	35,494,545
Puebla	1,587,928	1,532,860	1,808,453	1,622,038	10,370,240
Aguascalientes	775,247	772,223	1,183,815	497,659	6,303,868
Coahuila	745,353	1,108,253	1,085,979	553,313	6,758,210
Durango	300,491	426,206	695,906	277,007	8,477,033
Michoacán	44,492	125,356	123,105	125	576,137
Guanajuato	....	33,601	146,251	3,703	705,869
Nuevo León	1,325	60,729	242	8,421	161,307
Otros Estados	38,428	6,346,028	3,035,120	1,571,606	16,726,158
	67,327,828	86,553,669	73,411,608	54,211,646	584,683,839

[a] Datos proporcionados por el Departamento de minas de la Secretaría de industria, comercio y trabajo.

Producción general de cobre en México, 1890–1931, en toneladas

[Resumen formado con datos tomados de "Data referring to Mexican mining," por el inspector de minas Ing. Carlos Sellerier, México, 1901, y de Engineering and Mining Journal. Departamento de minas de la Secretaría de industria, comercio y trabajo.]

1890	4,300	1904	51,760	1918	70,200
1891	5,000	1905	60,963	1919	52,000
1892	6,300	1906	61,599	1920	48,000
1893	9,100	1907	54,476	1921	15,230
1894	11,200	1908	40,600	1922	26,978
1895	11,900	1909	57,300	1923	53,371
1896	11,600	1910	48,000	1924	51,837
1897	12,100	1911	56,400	1925	54,596
1898	13,700	1912	57,200	1926	56,521
1899	16,000	1913	52,800	1927	59,874
1900	22,050	1914	26,000	1928	67,327
1901	33,943	1915	22,000	1929	86,553
1902	36,357	1916	29,800	1930	73,412
1903	46,040	1917	45,000	1931	54,211

NOTA.—De 1890 a 1899 las minas El Boleo fueron las de mayor producción; en el año de 1898 produjeron 10,000 toneladas.

Mineral extraído y producción de cobre y otros metales provenientes de las minas trabajadas por cobre en México, 1922–31[a]

Año	Mineral (toneladas)	Producción (kilogramos)			
		Cobre	Oro	Plata	Plomo
1922	2,515,892	26,977,786	2,800	614,624	48,351,914
1923	2,781,617	53,371,852	2,601	461,189	42,209,681
1924	3,238,077	51,837,010	3,865	831,910	88,302,183
1925	4,924,780	54,596,160	4,723	971,285	94,787,727
1926	5,393,125	56,521,423	4,457	1,042,126	132,132,575
1927	5,936,754	59,874,857	6,146	1,331,353	211,055,904
1928	6,212,106	67,327,828	7,030	1,471,892	214,720,777
1929	4,998,538	86,553,669	5,243	1,090,624	174,697,168
1930	4,622,861	73,411,608	4,836	1,094,701	169,451,656
1931	5,015,255	54,211,646	6,370	1,191,728	213,460,637
	45,639,005	638,895,485	47,971	10,101,432	1,389,170,222

[a] Datos proporcionados por el Departamento de minas, Secretaría de industria, comercio y trabajo.

The Boleo copper area, Baja California, Mexico[1]

By Augustus Locke

Consulting geologist, San Francisco, California

History and production

Various German groups operated in the Boleo copper area during the 19th century, and the Compagnie du Boléo, of Paris, took possession in 1885. Small blast furnaces were built in 1886. In 1907 the harbor of Santa Rosalia, 6 kilometers from the mines, was improved, and since 1909 the annual production has averaged about 12,000 metric tons of copper. Reverberatory furnaces fired by fuel oil were built in 1920. Local gypsum was substituted for imported pyrite in smelting in 1923. About 1928 modern coal-mining machinery was installed, and the mines are now exploited like coal mines in flat sediments.

FIGURE 43.—Geology of central Baja California. (After Marland Oil Co.)

[1] Published by permission of the Compagnie du Boléo. The data for this paper were collected by the staff of the Boleo mines and by H. W. Morse, Roland Blanchard, Robert Marsh, Jr., and Augustus Locke in 1923 and 1924; by the Marland Oil Co. and M. E. Touwaide in 1926.

The mines are developed to depths of 250 meters (150 meters below sea level). The capacity of the plant is 15,000 metric tons of copper a year.

Production from the Boleo copper area

	Ore smelted (metric tons)	Copper (metric tons)	Recovery (percent)
1886–1901	2,098,670	113,992	(?)
1902–22	5,912,755	225,530	75 (?)
1923–32	2,513,050	101,430	88

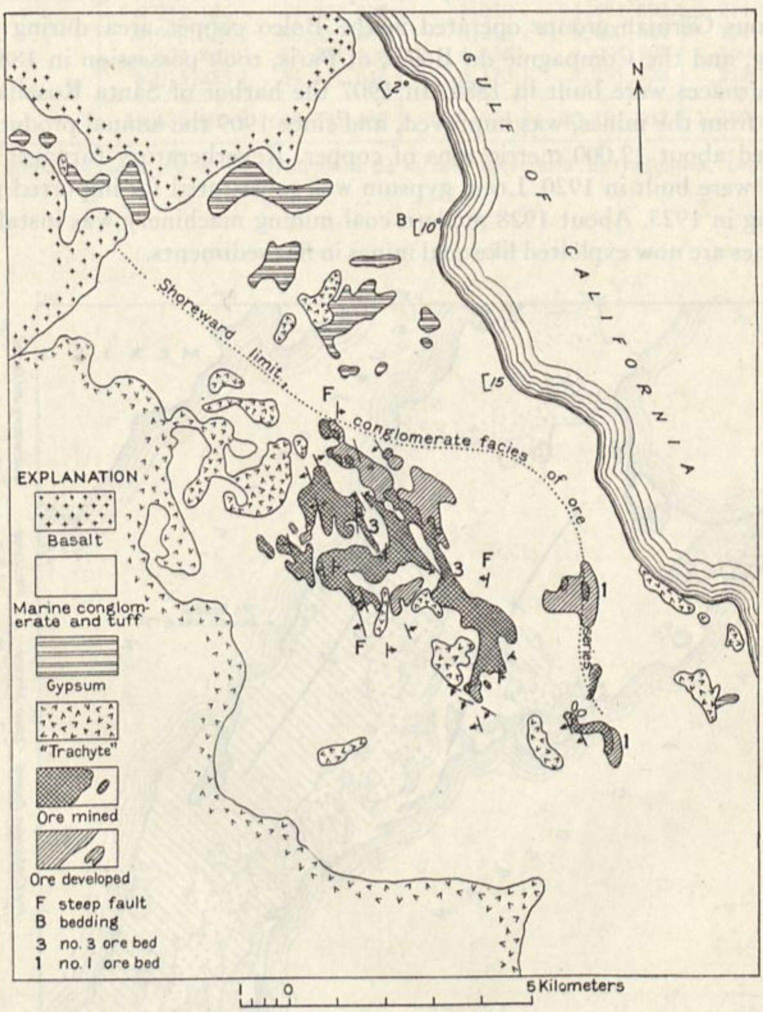

FIGURE 44.—Geology of the Boleo area, Baja California. (After Blanchard, Touwaide, and Compagnie du Boléo.)

Geologic setting

The peninsula of Baja California extends 1,100 kilometers southeastward as a narrow, elevated mass with its edges superelevated. Supposedly it was made by northeast thrusting and is bounded by northwest faults. Backbone mountains with peaks 3,000 meters high are continuous throughout the peninsula. In the north half this backbone is made principally of granite and metamorphic rocks; in the south half, of Tertiary continental rocks including a medial area of Tertiary or later basalt 200 kilometers long. Near the junction of the two halves the sediments, largely volcanic and mingled with flows, arch over the backbone from the west and slope eastward for 20 kilometers to the coast. (See fig. 43.)

The Boleo copper area lies on the east coast, in the east limb of the arch, at the latitude at which the basalt begins to appear.

The region surrounding the Boleo area is unmapped. The area itself measures 6 by 12 kilometers, extends along the shore line, and is a mesa sloping gently seaward. The rocks here make a basin of "trachyte" (an old local name for a volcanic group including rhyolite, andesite, and auganite) filled with beds of gypsum, tuffaceous conglomerate, and tuff. Because these beds steepen near the coast, definition of the shore by a monocline is suggested.

General section

The geologic section in and near the Boleo area may be summarized as shown below (2):

	Meters
Quaternary: Recent alluvium	0–5
Unconformity.	
Pleistocene:	
Terrace conglomerate	0–5
Unconformity.	
Basalt	0–10
Unconformity.	
Limy conglomerate	5–35
Coquina, with a thin tuff bed	2
Unconformity (?).	
Pliocene:	
Upper Salada, marine series (possibly Pleistocene?):	
Limy sandstone	15
Limy conglomerate with gypsiferous tuff	40–100
Unconformity (?).	
Lower Salada or ore series (marine):	
Tuffaceous sandstone	4–20
Clay ore bed no. 0 (poor, commonly eroded)	0–1.5
Sandy tuff (commonly eroded)	35
Clay ore bed no. 1 (productive)	1–4+
Tuffaceous conglomerate	0–50
Sandy tuff	50
Clay ore bed no. 2 (usually poor)	0–2.5
Tuffaceous conglomerate	15–40
Coarse tuff	1
Sandy tuff	10–45
Clay ore bed no. 3 (most productive)	1–3
Tuffaceous conglomerate	25–50
Sandy tuff	40–80
Clay ore bed no. 4	10±
Dolomitic limestone	1±

Unconformity.	
Age unknown:	Meters
Gypsum (discontinuous)	0–100
"Trachyte"	(?)
Pre-Cretaceous:	
Quartzite.	
Granodiorite.	

Basement rocks

The basin is 400 meters deep and measures 9 by 5 kilometers. It contains all the productive ground. Around the poorly exposed edge of this basin is "trachyte" overlain by gypsum. The "trachyte" floor is flattish and roughened by many small hills, of which some crop out and some are buried in the sediments of the ore series. Although several of these hills are bounded by faults later than the sediments, the sediments were laid on and around others.

Discontinuous gypsum, both bedded and massive, as thick as 100 meters, rests on the "trachyte." It is abundant on the seaward side of the basin. Its discontinuity and its origin are not understood. A large mass of anhydrite has been identified. The gypsum constitutes a downward limit or, where it rises as hills among the ore beds, the sideward limit of the ore.

A discontinuous crust of dolomitic limestone 1 meter thick follows the irregularities of the "trachyte" and gypsum floor.

The ore series

The beds of the ore series dip generally 15° ESE., but local dips are steeper. The beds are stepped up again and again toward the sea by steep "compensating" faults.

The tuff is well consolidated, generally sandy, and of coarse to fine grain. In composition it resembles the floor rock and is nearly fresh even close to ore. The tuff is water-laid. Its porosity has not been measured but is supposed to be high.

The ore series includes three beds of conglomerate averaging 30 meters in thickness, which thicken and become tuffaceous eastward. The conglomerate has a tuff matrix carrying subangular, ill-sorted fragments of the floor rock 0.5 to 30 centimeters in diameter; toward the top of the series, rhyolite and basalt fragments also come in. Like the tuff, the conglomerate is nearly fresh. Its beds constitute the more competent members in the series.

The ore beds are clay containing 30 percent of water, lying on conglomerate and under tuff, and were made by alteration of tuff coarser than the average. They are composed principally of cryptocrystalline "clay minerals" and calcite, with chalcocite, minor bornite, and chalcopyrite, in particles rarely larger than a pin head and commonly microscopic.

The rock fragments now visible as "ghosts" are angular and must have been softened after their deposition. Chalcocite was crystallized after the softening, for chalcocite veinlets cut across the layers, and crystals grew freely in a way demanding a soft matrix. None of the facts, however, deny that, in part, the clay and chalcocite came down with the sediment.

Ore bodies

The ore bodies have been mined to yield at least 2½ percent of copper. The stoped ground is elongated and ribbed with unmined intervals parallel with the coast line, with the coastward termination of the conglomerate beds, with the long axis of the "basin," with the vaguely mapped monocline on the coast side, with the principal direction of faulting, and with the principal structural features of Baja California. The stope floors are conglomerate; the roofs are tuff or clay; the material left in floor and roof contains not over 0.5 percent of copper. The side limits are made by "trachyte" or gypsum or assay walls. At least 10 square kilometers of bed containing 2½ percent of copper is supposed to remain within the general area of mining, in addition to higher-grade extensions outside that area. So far as is now known, the ore becomes thin and lean near the shoreward change from conglomerate to tuff.

Composite analysis of smelting ore (May–August, 1923)

H_2O at 110° C.[2]	28.00	SO_3	0.52
SiO_2	27.37	S	1.73
Al_2O_3	8.21	NiO, CoO, Mo	.46
FeO	7.42	Loss on ignition (includes water, CO_2, and carbon)	8.87
MnO	3.25		
CaO	3.53		98.51
MgO	3.02	Cu	4.90
CuO	6.13	S	1.93

The copper occurs principally in chalcocite grains of 0.001 to 0.2 millimeter. It occurs also in needles of chalcocite of the same order of size; in euhedral crystals several millimeters in diameter, showing orthorhombic external form or orthorhombic etch pattern and therefore developed below 91° C.; in irregular larger masses; in aggregates in combination with bornite and chalcopyrite grains, around kernels of chalcopyrite and rarely of bornite; and finally in fibers of chalcedonized wood (2). Instead of lying in open spaces, as is usual in other copper ore bodies, the sulphide here is embedded in a capillary or subcapillary matrix.

Touwaide (2) finds native copper in the sulphide ores as "minute disseminated grains" locally derived from bornite but commonly separate from the sulphides. He concludes that the native copper separate from the sulphides is contemporaneous with zeolites and not derived from the sulphides.

Pyrite is minor. Zeolites have been found sparsely. Barite is locally abundant. Carbon occurs commonly in a mist of small particles with no relic of organic form; in two analyzed specimens it makes 3 percent of the weight. In the lowest ore bed there are many fragments of chalcedonized wood containing chalcocite.

The ore is a slightly hardened blue clay of about the consistency of lignite. When exposed for a few days underground it cracks and even extrudes from the face. However, intrusions of ore along cracks into the wall rocks and extrusion from exposures in the walls of steep arroyos have not been recognized.

[2] The ore had already lost moisture by exposure to the air.

Although the erosion before and during the deposition of the cover has not been measured, it is possible that the top copper bed was never buried deeper than 100 meters.

Touwaide (2) concluded that the copper was originally present in the volcanic flows and tuffs (probably in the pyroxenes) to the amount of 0.2 percent. It was extracted thence, as he believed, by connate waters and penetrated the clay beds by diffusion, where it was precipitated as chalcocite, probably by H_2S or some other derivative of the organic matter in the clay. However, any such copper content as 0.2 percent in the fresh rocks is unproved.

A satisfactory theory of genesis of these ores must account for the geographic localization as well as the geologic occurrence in small, uniformly dispersed grains of dominant chalcocite in thin clay members interleaved with porous sediments of an igneous basin, as well as the fact that the chalcocite is in the low-temperature form. I am not ready to advance such a theory but suggest that further study may show that the Boleo copper traveled upward on crosscutting paths renewing those which guided the volcanic rocks, and that the ore bodies spread along porous zones from these paths. There still seems to be room for the bedding ores and the crosscutting ores to be parts of a single genetic system expressed in different rocks and structures.

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Copper deposits of the Cananea district, Sonora, Mexico[1]

By V. D. Perry

Cananea, Sonora, Mexico

Introduction

The Cananea district (see fig. 15 and pl. 21) was first worked by Jesuits in the 18th century, but mining operations were small and intermittent until 1900, when the rich Capote and Oversight mines were developed by Col. W. C. Greene. Since that time the district has been a consistent copper producer, and the discovery in 1926 of the high-grade Colorada ore body materially increased the developed and potential reserves.

A complex rock history, involving Paleozoic sediments, later extrusive rocks, and profound structural deformation with intrusion of deep-seated plutonic rocks, culminated in a period of widespread and intense mineralization.

The ore deposits are classified structurally into limestone replacement deposits along bedding and contacts, disseminated deposits in porphyry, and breccia pipes. The economically important ore bodies occur in more or less vertical pipe-like structures that break up through various host rocks and may or may not crop out. The Colorada is the largest and richest ore pipe in the district. Geologic evidence indicates that it is related to a plug of quartz porphyry and that the controlling structure is a pre-porphyry breccia pipe. Trapping of ascending ore fluids in this breccia, differentiation of these fluids into siliceous and metallic aggregates, further upward migration and deposition of the differentiated products, and finally postmineral brecciation constitute the indicated history of the ore body.

Recent developments at Cananea have added materially to available geologic information and thrown new light on many of the district's geologic problems. Where there is disagreement between more recent work and that done by earlier geologists, as compiled in the comprehensive survey of the district by S. F. Emmons (1) and his associates, it must be recognized that many additional data have become available since their work was published, in 1910.

R. H. Sales, chief geologist of the Anaconda Copper Mining Co., has given valuable assistance in discussing and aiding in the solution of Cananea's geologic problems. His help is gratefully recognized. It is likewise a pleasure to acknowledge the valuable cooperation of members of the Cananea geologic staff in the compilation and interpretation of new data and new ideas embodied in this

[1] Part of this paper has been taken from the Cananea chapter of an article compiled by R. H. Sales and D. H. McLaughlin on "Utilization of geology by mining companies," in the Lindgren volume of the American Institute of Mining and Metallurgical Engineers, 1933.

paper. In particular, recognition is made of valuable contributions by R. B. Mulchay on the problem of the Colorada ore body and by W. G. Valentine in identifying and remapping the rocks of the Cananea Mountains. Finally it is recognized that the policy of the Cananea Consolidated Copper Co. management in appreciating the value of applied geology in a mining operation has afforded the opportunity to continue this detailed geologic work.

Location and history

The Cananea district is about 25 miles south of the international boundary in the north-central portion of the State of Sonora, Mexico, about 50 miles by road from Bisbee, Arizona. The mines are in a short northwestward-trending range of typical Basin Range type.

It is reported that the first known operations in Cananea were conducted by the Jesuits about the middle of the 18th century, when the surface ores of the Cobre Grande mine were worked for their silver content. Later in the same century lead and copper ores from various parts of the district were mined by the house of Guea, of Chihuahua, and still later by José Pérez, of Arizpe, Sonora.

In 1865 General Pesqueira, with a party of 500 soldiers for protection against hostile Indians, established a camp at Ronquillo and built a small smelting plant. This operation was continued irregularly until about 1885; the matte from the furnaces was shipped to Swansea, Wales, by way of Guaymas, Sonora.

In 1881 the properties around Puertecitos, at the northwest end of the mountains, were purchased by a Cleveland (Ohio) company, and for the succeeding 3 years high-grade copper ore was mined and smelted. This venture was abandoned in 1884.

At the other end of the range the Cobre Grande and nearby mines were taken under bond shortly after 1886 by Major Morton for the F. Augustus Heinze interests. After about $110,000 in copper matte had been produced, Major Morton died, and the work was stopped.

In the immediately following years the control of the principal properties was acquired by Col. W. C. Greene, who began active exploitation of the mines in 1899, when the first smelting furnace was started. The discovery of the rich secondary copper ore bodies of the Capote and Oversight mines in 1900 and the construction of the first concentrator in the same year marked the beginnings of the modern operation. In 1901 a standard-gage railroad was completed to the border town of Naco, and in 1902 a narrow-gage railroad connecting the surface plant with the various mines was finished. The enterprise has been almost continuously operated since that time. The Colorada ore body, discovered in 1926, has provided a reserve of sufficiently high grade ore to enable continuous operation through the present period of depressed copper prices.

The corporate history of the various companies began with the organization by Colonel Greene in 1899 of the Cananea Consolidated Copper Co., a Mexican corporation. In 1900 the Greene Consolidated Copper Co. was formed in the United States as a holding company for the stock of the Cananea Consolidated Copper Co., and in 1906 the Greene Cananea Copper Co. was organized and acquired complete ownership of the earlier corporations. The Anaconda Copper Mining Co. in 1928, through an exchange of stock, assumed control of the Greene Cananea Copper Co. and has since operated it as a subsidiary.

Production

Records of the Cananea Consolidated Copper Co. show a total production to the end of 1932 of 1,185,009,802 pounds of copper, 22,697,472 ounces of silver, and 168,851 ounces of gold. Besides this output there has been some small production of lead, zinc, copper, silver, and gold by other companies, including the Democrata and the Calumet & Sonora. The total value of the metal output of the district from 1881 to the end of 1929 has been estimated at $200,000,000.

General geology

The rocks of the Cananea district consist of Paleozoic quartzite (Capote) and limestone (Puertecitos) capped by immense thicknesses of volcanic extrusives ranging from rhyolite to andesite, the whole invaded along lines of major structural deformation by a series of deep-seated granitic intrusives with final differentiates of diabase and quartz porphyry, probably of late Cretaceous age. The mineralized zone, about 6 miles long and 2 miles wide, follows the trend of the intrusive rocks, and both intrusion and mineralization coincided with a main regional axis of uplift along which Paleozoic sediments had been raised, folded, and distorted with relation to the volcanic rocks that flank the uplifted block.

Ore deposits

Limestone replacement deposits along bedding.—Typical limestone replacement deposits of chalcopyrite ore in which the mineralizing solutions have encountered and traversed bedding planes in the limestone are characteristic of ore bodies in the Elisa, Eureka, Sierra de Cobre, Capote, Veta, and Kirk-Democrata mines. In these deposits the mineralization was extremely erratic, the solutions having been only crudely selective, working out into a variety of beds and along minor fractures and folds, so that the sulphide ore occurs as irregular masses and splotches distributed through partly or completely garnetized limestone.

Limestone replacement deposits along contacts.—Steeply dipping contacts between limestone and relatively impervious rocks have provided ideal channels for ascending solutions. Where sharp folds occur or where the limestone contact is beveled off and capped by unconformable and impervious volcanic rock, traps or roofs have been afforded for the damming of ore solutions. Massive irregular chalcopyrite replacement deposits in the limestone directly beneath the Mesa tuffs in the Kirk-Democrata area and beneath the overlapping volcanic formations at the south end of the Oversight mine are excellent examples of this type of deposit.

At the Oversight, Sierra de Cobre, and Elisa mines there has been some shearing and slipping of the limestone along steeply dipping contacts where the relatively soft limestone has been buttressed against hard quartzite or igneous rocks. This shearing may have aided in localizing replacement deposits that are found along limestone contacts in these mines.

Many of these deposits have been raised to commercial grade by enrichment with secondary chalcocite.

Disseminated deposits in porphyry.—Crackled fractured areas in quartz porphyry or volcanic rock have served as loci for deposits that have been raised to commercial grade by enrichment. Such areas may occur in the fractured volcanic rock surrounding intrusive plugs, or they may overlie and apparently be the near-surface structural expression of underlying breccia pipes, as at the south end of the Veta mine, where a pipe in quartz porphyry grades upward into crackled but unbrecciated rock mineralized by the solutions that actively circulated through the central breccia channel.

Breccia pipes.—At Cananea the most productive ore deposits are localized within more or less vertical pipelike structures. The pipes may have acted as primary roots or feeders for overlying ore trapped in structurally favorable reservoirs, or they may themselves have been both the channelways and the reservoirs for mineralizing solutions. Where these structures are observed in the narrow vertical range between the surface and the present deepest level, 1,600 feet underground, they are isolated, sharply defined breccia pipes, usually oval or circular in plan and not connected laterally with through-going fissures. A study of their regional distribution indicates a systematic pattern and suggests that comprehensive premineral stressing of the district set up a deep-seated but weakly developed fracture pattern that provided a fundamental control both for injection of the latest intrusives and for localization of these mineralized breccia pipes.

The pipes of the district are classified under three types, which are described below.

Capote type: The Capote is a nearly vertical pipe, oval in plan section, in which the ore is scattered erratically through the entire pipe in enriched masses and bunches. The pipelike character of the deposit is definitely maintained through hard, relatively brittle rocks from the 1,600-foot level to a point 400 feet from the surface, where the structure intersects soft and relatively soluble limestone. There the identity of the original pipe is lost and the ore has spread laterally for several hundred feet through the easily replaced limestone. The ore body is thus shaped like a mushroom with a large massive limestone replacement body at the top and a stem of irregularly jumbled and mineralized angular fragments of quartzite, limestone, granite, and porphyries extending to and beyond the bottom level.

Duluth type: As contrasted with thoroughly brecciated areas of the Capote type, the Duluth breccia is a sharply defined oval ore ring, 1,200 feet long and 250 feet wide, encircling a weakly brecciated interior mass. The pipe reaches the present surface. Its downward extension cuts at right angles across a series of volcanic flows, tuffs, and agglomerates, and it has been developed to a depth of 1,400 feet. There is a striking resemblance between this pipe and the Nacozari pipe at Pilares, Sonora, Mexico.

Colorada type: Because of its size and its remarkable concentration of copper sulphides, the Colorada ore pipe is not only the most unusual but by far the most productive deposit in the district.

The ore body is ring-shaped in plan, 600 feet long by 500 feet wide at the sixth level. The ring converges downward, funnel-like, and merges into a solid ore pipe at the tenth level; the axis is vertical from the fifth to the tenth level but bends sharply and plunges to the northeast below that level. A wide ring of massive glassy quartz with a pegmatitic facies of coarsely crystalline quartz and phlogopite, defines the ore body in plan. The sulphides—bornite, chalcopyrite, and molybdenite with minor pyrite, tennantite, covellite, and chalcocite—are chiefly later than the quartz and occur as (*a*) a network of stringers in wall rock surrounding the quartz ring; (*b*) a network of veinlets intimately lacing the quartz; (*c*) a ring of massive sulphides, in part brecciated by postmineral adjustment, occurring adjacent to and inside the ring of quartz; (*d*) below the eleventh level as disseminated deposits or irregular lenses and masses in a pipe of pegmatitic, coarsely crystalline quartz and phlogopite.

Abundant geologic evidence indicates the following stages in the genesis of the ore body:

1. Pre-porphyry breccia pipe. The original pipe was either formed long before the intrusion of the porphyry or formed by the expansive force of gases advancing immediately ahead of the quartz porphyry magma column.

2. Secondary pipe within the primary structure. Starting at the 1,300 level, a secondary pipe developed in the southwest lobe of the main pipe structure.

3. Division of secondary pipe into an upper and a lower element. Advancing porphyry magma intruded into this secondary pipe was diverted across the core of the structure at the eleventh level and, congealing there, effectively divided it into a lower and an upper element.

4. Trapping of ore fluid in lower element of secondary pipe. Ore fluids injected along the southwest side of the primary channelway were diverted into the secondary pipe and trapped beneath a dome-shaped roof of massive quartz porphyry in the lower element of the secondary structure.

5. Differentiation of ore fluids. Under conditions of high temperature and pressure the ore-bearing material segregated into aggregates of quartz and copper sulphides within the lower element of the secondary structure.

6. Injection of differentiated products. Under the accumulation of gas pressure and probably also because of chemical attack, the porphyry roof of the lower element finally ruptured, permitting the escape of successive surges of quartz and copper sulphides into the upper element of the pipe. In this part of the structure the quartz crystallized as an upward-expanding ore ring with a subsurface apex at the 500 level. Copper sulphide and molybdenite followed the quartz and crystallized as a network of veinlets lacing quartz and surrounding wall rock and as a ring of massive sulphides inside the ring of quartz. The top of the ore body is from 500 to 800 feet below the surface.

7. Postmineral brecciation of core. Thorough kaolinization of the ore-body core weakened the rock sufficiently to cause slumping of the interior mass. This slumping brecciated sections of the high-grade sulphide ore, as well as part of the altered but relatively unmineralized porphyry.

Conclusions.—Limestone replacement deposits along bedding planes and along contacts, disseminated deposits in porphyry, and breccia pipes of various types characterize the ore deposits of the Cananea district. Marked differences in these ore bodies are due to variations in the character of mineralizing fluids, to differences in the host rocks, and finally to complexities in structural environment. There are no through-going fissures that might have served as channelways and places of deposition for ascending ore fluid. Instead, this material has circulated through and been diverted and trapped in a variety of structural features, either inherent in the older rock pattern or in restricted, more or less vertical breccia-pipe systems that break upward through these different formations.

Enrichment acting on mineralized porphyry areas, on limestone replacement bodies, and on outcropping breccia pipes has formed valuable deposits of secondary chalcocite. Until the discovery of the high-grade primary Colorada ore body these secondary deposits were credited with most of the district's production.

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The Pilares mine, Los Pilares de Nacozari, Sonora, Mexico[1]

By J. B. Tenney

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History and production

The prominent hard copper-stained outcrops over the central portions of the mineralized pipe or oval of the Pilares mine, at Los Pilares de Nacozari, Sonora, Mexico, were probably discovered at an early date. In the early nineties the property was acquired by the Guggenheims, who developed the mine considerably. The inaccessibility of the district and the absence of high-grade ore were discouraging factors, and in 1896 they sold the mine to Phelps, Dodge & Co. Under the management of this company the property was rapidly developed, transportation difficulties were overcome by the building of a railroad from the mine to Douglas, Arizona, and the mine was thoroughly equipped to produce on a large scale. The ore has been almost entirely treated by concentration, and the concentrates were shipped to the company's smelter at Douglas.

Production on a substantial scale started in 1904 after the completion of the railroad and the smelter at Douglas. It continued without interruption until the collapse of the copper market in 1931, when the property was closed indefinitely. The production from 1902 to 1925, as published in the Copper Handbook and the Mines Handbook, was about 575,000,000 pounds of copper, 4,000,000 ounces of silver, and 11,300 ounces of gold.

Topography and location

The Pilares mine of the Moctezuma Copper Co. is about 75 miles south of the international boundary and about 7 miles east of Nacozari de García. (See pl. 21.) It is at an altitude of 5,000 feet in one of the northward-trending ridges that form part of the mountain mass that culminates in the Sierra Madre de México. To the east, south, and west the topography is rugged; to the north less so. The mountain ranges rise abruptly from the plains and are of characteristic Basin Range structure.

Nacozari de García, 7 miles from the mine, is connected with the Southern Pacific Railroad at Douglas, Arizona, by a 77-mile broad-gage railroad. The concentrator at Nacozari is connected with the mine at the 700-foot level by a 6-mile steam railroad of 30-inch gage, which runs through the 5,000-foot Porvenir tunnel.

Nacozari is in the valley of the Moctezuma River, one of the headwater tributaries of the Yaqui River. The mine, in the mountains east of the river valley,

[1] This description is taken from papers by Wade and Wandke (1) and Locke (2) and from a personal communication by Donald D. Smyth, chief geologist at the mine at the time of closing.

is close to the divide between the Moctezuma drainage basin and that of the Bavispe River, also a tributary of the Yaqui.

Geology

Rocks of the district.—All the rocks in the vicinity of the mine are igneous. They consist of volcanic tuffs and breccias and intrusive rocks into them. The extrusive rocks consist of latite, andesite, and dacite tuffs and a few thin flow members. The total observed thickness is over 3,000 feet (914 meters). In the mountains west of the town of Nacozari, a range parallel to the one in which the Pilares mine is found, remnants of folded limestone are interbedded with clastic rocks and an older series of volcanic rocks, of unknown age, intruded by granodiorite, on which the Pilares series of volcanics rests. The age of the extrusives has been assumed as early Tertiary or late Cretaceous, largely through their correlation with extrusives near the international boundary south of Douglas, which overlie the beveled edges of Cretaceous sediments (1, p. 382).

The principal intrusive rock of the district is a fine-grained holocrystalline rock of the general composition of a diorite with some more acidic monzonitic phases. This rock occurs mainly as a thick sill between the dacite tuff basal member of the extrusive series penetrated by the lowest mine levels and the overlying andesite (3). Smaller dikes also cut the andesite and latite. Of distinctly later age are relatively small dikes of more basic composition, which have been so much altered by supergene waters that their exact composition is not known. The dikes, many of which cut the ore bodies, are called "caliche" dikes by the miners.

In the ranges east and west of the mine there is exposed at the base of the volcanic series plutonic coarsely crystalline granodiorite which may possibly underlie the whole region as a large batholithic mass. The contacts are generally mineralized with copper salts, locally concentrated as commercial ore bodies (3).

Structure.—The extrusive rocks lie generally flat. They have been broken extensively by normal faults. West of Nacozari the limestone and granite basement rocks crop out as an eroded synclinal basin, which is in most places separated from the later extrusives by a normal (?) fault of some magnitude (1, p. 382). The general structure of the region is typical of the Basin Range province. The mountain range west of Nacozari occupies a former structural trough, which was subsequently raised in a general upwarp of the whole region, and the detrital matter probably was scooped out by subsequent streams.

At the mine the extrusive rocks form a sharp unsymmetrical synclinal basin 2,000 feet long by 1,000 feet wide, striking northwest and pitching southeast (1, p. 385). The development of the syncline was controlled by a great series of faults of minor throw in its central portion and by a strong circumferential fault with a throw of 100 to 200 feet. Generalized longitudinal and cross sections of the mine are shown in figures 45 and 46. Within the synclinal trough the extrusives and small irregular dikelike masses of monzonite and quartz diorite are generally broken or "crackled" into fragments as much as 10 inches in diameter, but some larger fragments reach 40 feet in diameter (1, p. 387). The greatest brecciation is in a zone about 50 feet thick on the outer periphery of the trough,

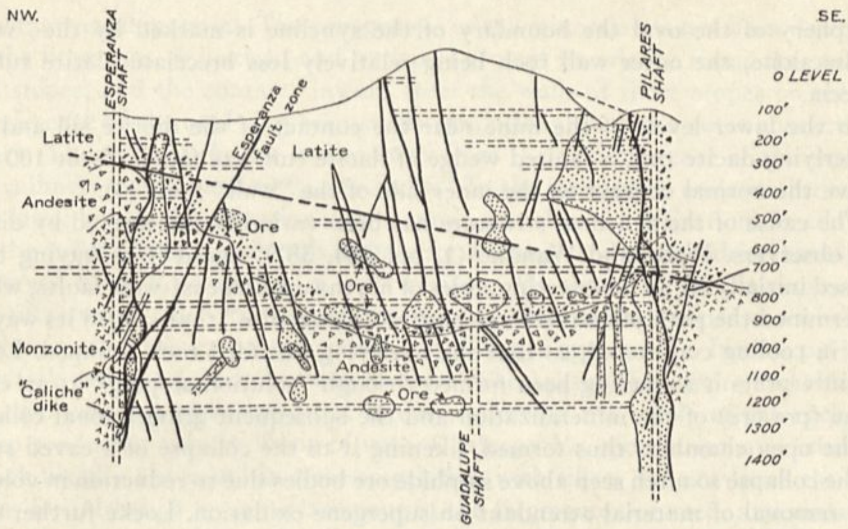

FIGURE 45.—Vertical section through mine oval from Esperanza shaft to Pilares shaft, Pilares mine, Sonora, Mexico. (After Wade and Wandtke, 1920.)

where it has reached the stage of "jumbled breccia, resembling the rock filling of a caved stope" (2, p. 433). Throughout the extensively brecciated mass within the oval, but especially near the sides, the latite and andesite are vuggy. This is more especially true of the more siliceous and brittle latite breccia. Most of the vugs are lined with calcite or quartz, some with chlorite and specularite, and a few with sulphides (1, p. 389). To a depth of 400 feet from the surface on the

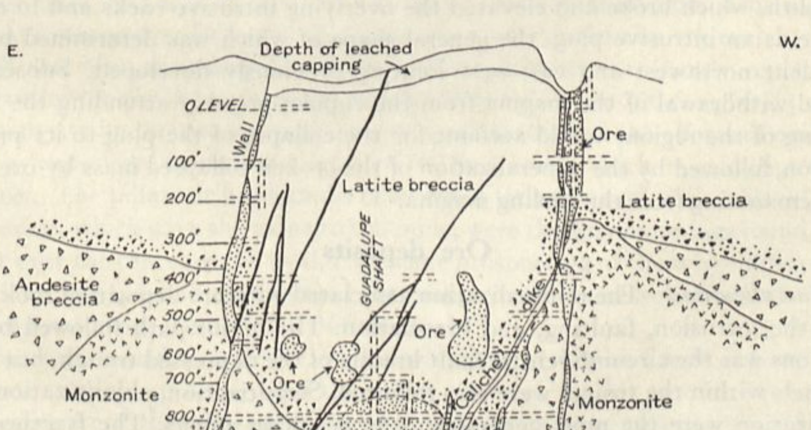

FIGURE 46.—Vertical section at right angles to mine oval through Guadalupe shaft, Pilares mine. (After Wade and Wandtke, 1920.)

periphery of the oval the boundary of the syncline is marked by the "wall" faults alone, the outer wall rock being relatively less brecciated latite tuff or breccia.

In the lower levels of the mine near the contact of the diorite sill and the underlying dacite tuff, a faulted wedge of dacite tuff was found about 100 feet above the normal contact on the inner side of the "wall" fault (3).

The cause of the synclinal structure has been variously interpreted by different observers. Wade and Wandke (1, pp. 384, 387) regard it as having been caused initially by an intersecting series of northwest and east-west faults, which determined the path of an intrusive plug of "monzonite" that stoped its way up and in cooling contracted, so that the overlying intruded rock slumped. Locke (2) interprets it as having been formed through "solution stoping" at an early stage (pre-ore) of the mineralization and the subsequent gravitational collapse of the open chambers thus formed, likening it to the collapse of a caved stope or the collapse so often seen above sulphide ore bodies due to reduction in volume and removal of material attendant on supergene oxidation. Locke further conceives that the collapsed breccia pipe subsequently formed the pathway for later solutions carrying the ore minerals.

Smyth's interpretation (3), based on the evidence of the lowest levels, differs from that of Wade and Wandke, as the sill-like form and brecciation of the "monzonite" (diorite) preclude its being the upper chilled phase of a batholithic cupola. The evidence presented by the faulted segment of dacite on the inner side of the wall fault suggested the following explanation. Smyth believes that the whole area was intruded by a batholithic mass of granodiorite and that the Pilares "oval" was initially caused by the upward pressure of a cupola on the batholith, which broke and elevated the overlying intrusive rocks and forced in diorite as an intrusive plug, the general shape of which was determined by the prevalent northwest and east-west jointing previously developed. Subsequent partial withdrawal of the magma from the cupola, possibly attending the block faulting of the region, would account for the collapse of the plug to its present position, followed by the mineralization of the broken collapsed mass by ore solutions emanating from the cooling magma.

Ore deposits

Mineralization.—The mineralization associated with ore deposition took place after the intrusion, faulting, and brecciation. The major path followed by the solutions was the circumferential fault breccia of the depressed trough, but other channels within the trough were also followed. Sericitization, chloritization, and pyritization were the most general and far-reaching effects. The fractures between breccia fragments were filled, and the solutions worked out into the fragments themselves by replacement. More localized solutions, which followed the same general paths, deposited silica and chalcopyrite, usually associated with specularite and small amounts of scheelite, in the fractures, and partly replaced the fragmental material. The paragenesis of the minerals has not been described in the literature. Sericitized and pyritized ground invariably forms the walls of the stopes, and the contacts inward from the walls of those stopes on the circumference of the oval ring are usually gradational, but the outer contacts are sharp. The walls of the ore bodies away from the circumference of the oval are prevailingly gradational or "assay walls." In the more basic andesite breccia of the lower levels, chloritization was common as well as sericitization. In addition to the more common minerals, sphalerite, bornite, and tetrahedrite have been observed here and there and a little barite in the upper levels. To summarize, sericitization or chloritization was intense and affected the breccias as a whole by replacement of the rock fragments and by filling of open cracks. Intense pyritization followed but did not travel as far from the cracks as the sericite and chlorite. Silicification was more local but intense, affecting the whole of the rock and often producing a drusy lining of vugs. Chalcopyrite, specularite, and scheelite, which usually are found in close association with silica, did not leave the fractures far, although some replacement of the fragments occurred, and masses of high-grade ore weighing as much as a ton or more have occasionally been found. Typically the ore is a network of chalcopyrite and pyrite veins cementing angular fragments of sericitized or silicified latite or andesite, which have been replaced for only short distances inward by the ore sulphides. The unreplaced fragments are so varied in shape and generally so small that hand sorting of ore and waste is impracticable.

Oxidation and enrichment.—Oxidation effects at the mine are very shallow, in spite of the prevailing aridity of the climate. The outcrop of the main ore zone around the periphery of the oval occupied a depressed zone, was devoid of copper stain, and was colored reddish brown from oxide of iron. This cap rock did not average over 50 feet in thickness and was underlain by the enriched zone, which was also comparatively shallow. All sulphides were partly replaced by chalcocite to a depth between 100 and 200 feet. Below the 200-foot level primary chalcopyrite and pyrite were encountered, which showed the effects of oxidation only by superficial tarnish to a depth of 700 feet, below which no oxidation effects are seen. The pillars or hard knobs of silicified latite stained with malachite and iron oxide, which gave the name to the mine, were the first croppings found. They occur over the center of the oval. Extensive prospecting of them by undercutting failed to find ore and discouraged for many years the search in depth for ore bodies away from the periphery of the oval.

Distribution and tenor of ore.—The principal ore bodies are in a nearly continuous envelope of ore around the rim of the oval. In this envelope the largest ore bodies are at the two ends of the oval, where very large masses with maximum dimensions of 1,000 feet long by 300 feet wide by 800 feet deep were stoped. Away from the two ends the ore bodies are smaller. Within the oval the central ore bodies are smaller and more irregular in shape. A horizontal projection of the Pilares ore bodies is shown in figure 47.

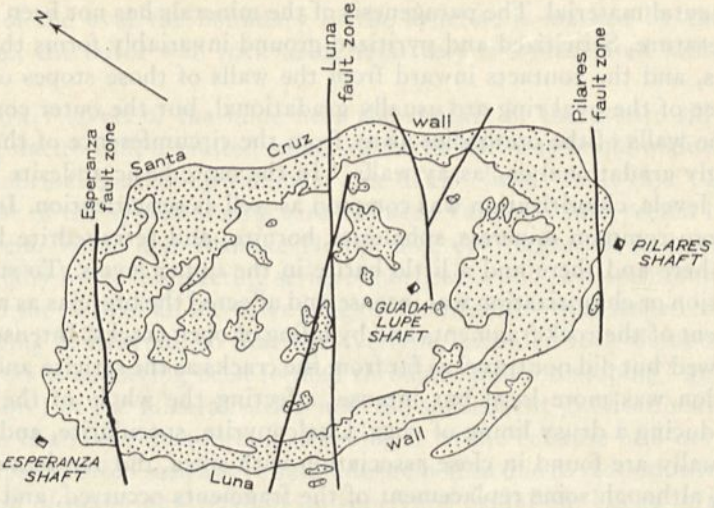

FIGURE 47.—Pilares ore bodies projected on a horizontal plane. (After Wade and Wandke, 1920.)

The grade of the ore ranges from the lower economic limit up to over 10 percent in copper, and the ore as milled has averaged between 2.5 and 3 percent. Small amounts of silver and gold accompany the copper.

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Breves noticias del cobre en Cuba

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Desde luego, parece fuera de toda duda, que los yacimientos cupríferos de la República de Cuba se hallan en íntima relación con los magmas básicos que por doquier asoman en el suelo de casi todas sus provincias. En unos casos su relación podemos decir que es inmediata, pues los encontramos dentro del magma peridótico mismo (este tipo de criaderos, sin embargo, parece ser no muy frecuente); en otros (hay varios ejemplos de ello), es en el contacto de dos magmas ígneos de diferente época donde se ha provocado la precipitación de las soluciones cuprosas: este es el caso de los contactos homogéneos. En otros casos un contacto heterogéneo ha sido el determinante de la precipitación de las soluciones de cobre. Por último, para que nada falte en la metalogenia de este metal, dentro de la República, en el transcurso de la monografía que del mismo publicamos, pueden apreciarse criaderos de origen ígneo en las primeras precipitaciones seguidas de la intervención de los fenómenos de soluciones hidrotermales en el relleno de los depósitos de las menas de este metal.

Hecha esta rapidísima disquisición geológica general, respecto a los yacimientos de cobre, vamos a pasar a dar siquiera una ligera noticia de los más principales, sin detenernos en consideración geológica alguna particular sobre cada uno de ellos; pues que ella la ha de hallar quien en ello esté interesado, en la antes citada monografía.

Es el cobre, sin género alguno de duda, sino el más, uno de los metales más importantes del subsuelo cubano, tanto en lo que se refiere a su cuantía, como en lo que se refiere a la alta calidad de sus menas.

El conocimiento y beneficio del cobre en Cuba, data de fecha muy remota; tan lejana, que hay quien lo supone explotándose muy pocos años después del descubrimiento de la América por Cristóbal Colón. El primer fundo minero conocido y explotado por los descubridores es el desde muy antiguo conocido con el nombre de minas de "El Cobre," muy próximo a la ciudad y próximamente hacia el oeste de Santiago de Cuba, y cuyo nombre en el mercado mundial de dicho metal, ha perdurado a través de un buen número de siglos.

En aquellos remotos tiempos puede decirse que la producción de cobre en la República, se circunscribía al cobre de aquellas minas. Pocos son sin embargo los datos estadísticos que se poseen de estos tiempos. Una memoria que de las mismas publicó D. Diego López de Quintana en 1853 nos hace conocer que en el lapsus de tiempo que media entre los años 1843 y 1850, la producción ascendió a unas 345,240 toneladas de cobre, haciendo de paso notar, que algunos embarques de las mismas cubrieron un promedio de un 50 por ciento de ley en cobre metálico. A partir de esta fecha, cuantos ingenieros se han ocupado de estas minas, lo han hecho más bien bajo el punto de vista técnico, ocupándose poco las compañías de lo dispuesto por la ley de minas, en lo referente al cumplimiento de lo que la misma dispone, respecto al aporte de datos estadísticos de producción. En estas condiciones llegamos al año 1908, en que aparecen los primeros datos estadísticos. A partir de esta fecha y hasta el año 1913, en que se descubren las hoy famosas minas de Matahambre en Pinar del Río, puede decirse, que la producción de cobre en la República, sigue circunscribiéndose a la producción de estas minas; y así hasta aquella fecha la producción monta a unas 311,900 toneladas; y como quiera que en igual fecha los datos relativos a la exportación, aparecen apreciadas las toneladas a 350,705, fácil es de deducir, que las minas no permanecieron completamente inactivas, con anterioridad a la fecha de 1908. Con posterioridad al 1913 trabajaron en distintas épocas, sobre todo cuando en Europa se desencadenó la gran guerra.

Ya en explotación las minas de El Cobre, y en una memoria de D. Carlos Abouin, cuya fecha desconocemos, aparece descrita en el término de Dumañuecos cerca de Victoria de las Tunas; y a tres leguas de la costa norte, en la propia provincia, la mina Victoria, en la que describe (véase la monografía del cobre) este importante yacimiento, tanto por lo que se refiere a la extensión de su gossam, como a la bondad de sus menas, llamando la atención sobre la necesidad en aquella época de un estudio científico más amplio, sobre este yacimiento. Las labores en estas minas fueron muy superficiales, habiendo según se desprende de la memoria antes citada sucumbido por fin la mina por escasez de capital. De todas formas por los datos que en ella se apuntan son dignas estas minas de volver a tomarlas en consideración.

Modernamente y cuando la gran guerra azotaba a las naciones europeas sobrevinieron tanto en esta como en las demás provincias de la República, multitud de denuncias de cobre, que fueron objeto de exploraciones más o menos activas, sin embargo no llegaron a convertirse en realidades mineras.

Entre éstas y en esta provincia de Oriente, existe un grupo de denuncias, constituido por las nominadas "La Nuez," "Pepin" y "Ana," que poseen unos magníficos afloramientos de hidrocarbonatos de cobre y de cobres grises. Su ley en cobre varía entre el 18 y el 50 por ciento, con proporciones de plata variables entre 63 y 72 onzas en toneladas de 2,000 libras.

Siguiendo nuestro recorrido a través de la República, de oriente a occidente, penetramos en la provincia de Camagüey. Las minas más antiguas que en esta provincia se conocen se localizan en la región de Bayatabo, que se sitúa a unos 8 kilómetros al este del poblado de Minas.

Una memoria del ya citado D. Carlos Abouin, concede gran importancia a estas minas de cobre, generalmente muy ricas, haciendo notar al propio tiempo la presencia, sobre todo en la antigua mina San Antonio, del plomo, el zinc y el estaño. Allá por los años de la guerra mundial fueron tomadas nuevamente estas minas por una compañía americana, a cuyo frente se hallara el ingeniero Mr. Adams. Según noticias recogidas sobre el terreno, las labores de reconocimientos llevadas a cabo por aquella compañía, confirmaron lo ya descrito por el Sr. Abouin, y la compañía parecía dispuesta a ponerlas en explotación, cuando sobrevino la paz y con ella y al poco tiempo la depreciación del cobre—cosa que condujo al retraimiento de la compañía.

Con el principio de la guerra mundial, se suscitó también en la provincia de Camagüey, la fiebre de descubrir nuevas minas de cobre, llevando los exploradores sus actividades sobre los valles de Limones y Guadalupe, principalmente.

En el primero aparte de otras denuncias surgieron las que en 1919 fueron objeto de un informe rendido por la Corporación técnico industrial minera, que fué llevado a cabo por el que esto suscribe en unión de su compañero D. Manuel G. Lago. Dicho informe, que puede verse en la monografía del cobre, fué francamente favorable en el estado en que se encontraban las labores de reconocimiento.

En el valle de Guadalupe, se llevaron a cabo por la misma época importantes trabajos de exploración de los que se llegaron a obtener cantidades apreciables de buenos cobres, algunas de cuyas partidas llegaron a negociarse en el mercado americano. Minas hay en este valle merecedoras de volver a ponerse en movimiento.

Dicho lo que antecede con respecto a la provincia de Camagüey y siguiendo el orden adoptado, pasemos a la de Santa Clara. En esta provincia son también conocidas desde muy antiguo las minas de cobre. Hay noticias de que con anterioridad al año 1836 se explotaban ya las minas conocidas por el nombre de minas de "San Fernando" en el hoyo de Manicaragua, término municipal de Santa Clara. Mas es hacia el año anteriormente citado, cuando Mr. M. B. Smith y Mr. H. Bradford, constituyeron una sociedad con 150,000 pesos de capital para poner en marcha este coto. Quien esté interesado puede ver en la antes citada monografía, cuantos pormenores desee de las referidas minas y de la cual estractamos las presentes líneas.

El año 1857, fueron visitades estas minas, por el Profesor D. T. Ansted, el que nos dá cuenta de la existencia de dos filones en desigual estado de explotación; siéndolo con más intensidad el situado más al norte. Para la explotación de los referidos filones se abrieron unos 10 pozos en una longitud de unos 726 metros. Su potencia se estimó en unos 10 metros, y los pozos más profundos, bajaron a 32 brazas. Se embarcaron con anterioridad a 1856 unas 10,000 toneladas de mineral de cobre para Cienfuegos de una ley del 17 por ciento, y en 1856, 480 toneladas para Swansea, Gales, de la propia ley y 300 para los Estados Unidos, que también se supone fueran de la misma ley. Según un análisis practicado por Frederic P. Dewey presentan estas minas 4.5 onzas de plata y 0.15 onza de oro por tonelada de 2,000 libras. Posteriormente fueron visitadas estas minas por el inspector general del Cuerpo de Minas, D. Gabriel de Usera, y en los diferentes análisis que presenta, no se acusa presencia de plata ni oro alguno. Más adelante el célebre químico Maigrot, insiste nuevamente en acusar la presencia de oro y plata en aquellas menas.

Por fin, hacia las postrimerias de esta explotación minera (no se sabe a ciencia cierta la verdadera causa de su abandono) el inspector general del Cuerpo de Minas D. Pedro Salterain, intrigado sin duda por estas diferencias de criterio realizó por su cuenta análisis sobre muestras de mineral tomadas de los mismos sitios que decía haberlas tomado Mr. Maigrot, obteniendo como resultado la perfecta ausencia en los análisis, del oro y la plata mas obteniendo leyes de cobre oscilantes entre un 6 y un 37 por ciento en metálico.

Como resultado del curso de las investigaciones sobre estas minas parece que por regla general, las menas empobrecen en el techo y enriquecen en el muro; y en vista de su alto por ciento en cobre debieran tomarse de nuevo y ponerlas en explotación, pues las profundidades alcanzadas por los pozos más hondos, no son ni mucho menos profundidades límites.

Otra de las minas que desde antiguo, se conocen también en la provincia de Santa Clara, es la que con el nombre de "San José" se localiza en el cuartón de San Gil, en el barrio de Malezas del municipio de Santa Clara, a unos 9 kilómetros de la propia ciudad. Fue solicitada la concesión en 1866 por el Sr. Juan Ignacio Selgas y demarcada en 1867 por D. Pedro Salterain, en cuya acta de demarcación se hace constar la existencia de un pozo entibado de 7.80 metros de profundidad, aparte de otras labores. En 1887 fué objeto de nueva denuncia por D. José Gutiérrez y Gutiérrez, por haber caducado la anterior, siendo demarcada en 1888 por el ingeniero D. Gabriel de Usera.

En la tantas veces citada monografía del cobre damos a conocer un informe sobre esta mina, debido al ingeniero de minas D. José I. Corral, del que como resumen se viene a deducir, que los caracteres exteriores de esta mina la hacen recomendable, toda vez que las labores en ellas practicadas son muy someras y de no gran desarrollo, en relación a la gran montera de pórfido diorítico, ferruginoso, con hidrocarbonatos de cobre que presenta. Las monteras en este criadero son dos—una como de 50 metros de ancho y otra como de 20 metros, manifestándose dispuestas paralelamente tanto en dirección como en pendiente. Merece esta mina por tanto un reconocimiento a mayor profundidad que el que acusan las labores, en la referida memoria reseñadas.

El descubrimiento de las llamadas "Minas Ricas" en esta propia provincia, se remonta según la leyenda, a épocas anteriores a las de las guerras de Independencia. Se sitúan a unas 4½ leguas de Fomento y a unas 3½ de Manicaragua. Su primitiva exploración, según la referida leyenda, se atribuye, a la insaciable búsqueda del oro por los conquistadores. Nos dice también la misma, que algunos años más tarde, una compañía americana, siguiendo las huellas de aquéllos, logró mediante trabajos de alguna consideración, localizar el filón de oro que aquellos perseguían, y que una vez logrado el objeto lo taparon y levantaron el campo. Esto es lo que dice la leyenda de estas minas; y como leyenda puede pasar. Lo que hay sobre el particular respecto a estas minas, es la existencia de un buen criadero de cobre. Sus menas y en general las condiciones exteriores todas del yacimiento, son todas idénticas a las de la mina anteriormente citada de San Fernando en el hoyo de Manicaragua. La única condición desfavorable al presente, se encuentra en su alejamiento de cómodos medios de transporte.

Por lo que a este metal se refiere en la provincia de Matanzas, hemos de decir, que aunque se han denunciado un buen número de ellas en la misma, solamente una, la conocida por el nombre de "Vigilante," es la que hasta la fecha ha dado perspectivas de yacimiento industrial. Se localiza dicha mina, en la finca Recreo en el barrio de Corral Nuevo, municipio de Matanzas. La mena, muy limpia, está constituida por un sulfuro de cobre no muy bien determinado, pues el Geological Survey de Washington, la considera—con alguna reserva—como bornita. Según pude apreciar sobre el terreno, parece que se trata de un contacto entre la serpentina (peridotita) y una roca metamórfica, cuya especie ha quedado indeterminada también por aquella superior autoridad. La especie mineral, se presenta con color negro, con reflejos bronceados, mostrando un alto tenor en cobre.

Parece ser una buena perspectiva, tanto por la bondad de sus menas, como por su proximidad a la costa y al ferrocarril de Hershey.

La minería del cobre en la Habana, apenas si representa un valor histórico. Poco después de haberse descubierto las minas de "El Cobre" en Santiago de Cuba, se extrajeron de una mina, cercana a Bacuranao, unos cuantos centenares de quintales de un mineral de cobre de alta ley. Hay denunciadas varias minas en la provincia, mas parece que el resultado no ha respondido a las esperanzas de los denunciantes.

Pinar del Río es la provincia donde más y más importantes yacimientos de cobre existen en la República. La minería de este metal en esta provincia, data del año 1830, en que se denuncia y explota en Viñales, la mina Nuestra Señora del Rosario, de la que se embarcaron unas 30,000 toneladas de sulfuro de cobre de 18 por ciento de ley. Actualmente se conoce esta mina y las colindantes con el nombre de mina "Constancia," y con este nombre se vino explotando en los años que duró la guerra europea, hasta el 1920.

Allá por el año 1840, se denunciaron y empezaron a explotar, en el término municipal de Mantua, las minas Unión, Complemento y Adición. Dicha explotación, que se llevó a cabo en varias etapas, duró hasta el año 1868. Como puede verse en la memoria que de este grupo se inserta en la monografía de este metal, las menas que salían de las minas, tenían diferente riqueza y eran de consiguiente sometidas según la ley, a distintos sistemas de beneficio. Los minerales del ½ al 3 por ciento en cobre, se beneficiaban, por el procedimiento de cementación. Los superiores al 3, mas inferiores al 10 por ciento en cobre, eran sometidas a la fusión en hornos castellanos y de reverbero. Las del 10½ por ciento, se lanzaban directamente al mercado. Como resultado de este sistema de beneficio, se obtuvieron 20,000 quintales métricos de pirita cobriza del 10 por ciento como promedio; 6,000 quintales de matas de primera fusión del 20 al 30 por ciento en cobre; 8,340 quintales de cáscara de cementación del 68 por ciento en cobre; 3,400 quintales de cobre nativo y como de 200 a 240 quintales de cobre roseta.

Hacia el año 1913, es decir un año antes de declararse la guerra mundial, comenzaron los trabajos de exploración y explotación del cobre, en la mina Gustavo Alfredo, en esta propia provincia, más conocida por el nombre de mina de "Matahambre." Una cacería de venados, sorprendida por un fuerte aguacero, hizo que el Sr. Victoriano Miranda se cobijara por casualidad debajo de uno de los crestones de esta mina. En la cobija, dicho señor notó la presencia de piedras verdes y azules; lo que le llamó la atención, y tomando algunos trozos de ellas, se las llevó al Dr. Alfredo Porta, en aquella ocasión farmacéutico en la ciudad de Pinar del Río. El Dr. Porta las analizó, y visto el resultado, se encaminó a la Habana, en busca de capital para poner en movimiento dichas minas, teniendo la oportunidad de dar con el Sr. Manuel L. Díaz, ingeniero a la sazón de los ferrocarriles. Convenidas las condiciones del negocio, se trasladaron al lugar de las minas, comenzando poco después la exploración de las mismas; habiendo estado la dirección de los primeros trabajos, a cargo de Mr. Morse.

Pasando por alto un sin número de vicisitudes que en el principio ocurrieron, en este yacimiento, hoy el primero en Vuelta Abajo, diremos que en la actualidad se trabajan estas minas por una compañía americana, subsidiaria de la American Metal de los Estados Unidos de América.

En los primeros niveles, la explotación fue hecha por medio de socavones, siendo la ley de los todos unos de mina la del 12 por ciento en cobre. Esta ley promedio fué descendiendo a medida que las labores ganaban en profundidad hasta las de reconocimientos actuales, que alcanzan una profundidad, próxima a 2,000 pies, con un 5 por ciento en cobre. Se trabaja sin interrupción en estas minas desde 1913, obteniéndose actualmente una producción de 600 toneladas diarias. Trabajan en las diferentes faenas de la mina, como 1,000 obreros, y ya hoy Matahambre es un verdadero pueblo.

Puede también decirse, que desde aquella fecha, la producción total de cobre en Cuba, proviene de estas minas. Un estimado por lo bajo, de lo que estas minas han producido desde la iniciación de las labores hasta el año 1925, lo tendremos, calculando la producción diaria en 400 toneladas, estimando la ley de los todos unos en un 8.5 por ciento en cobre, media entre la más alta (12 por ciento) y la más baja hasta la fecha (5 por ciento). Con estos dos factores durante los 12 años que lleva de existencia la mina, la extracción ha seguramente pasado de 2,528,000 toneladas, las que por lo bajo han debido producir 214,880 toneladas de cobre metálico; que traducidas a libras, son tanto como 429,760,000 y que a razón de 12 centavos libra, se resuelven en 51,571,200 pesos—algo más de $4,000,000 por año. Si de la cantidad expresada, retiramos a gastos y pérdidas las tres cuartas partes, nos quedará como utilidad la cantidad de $1,000,000 anualmente.

Ante este resultado, hemos de convenir, que la minería de cobre en la República es, más que un fracaso (como algunos pretenden) el más lisonjero de los éxitos.

Siguiendo en importancia, con relación a la cantidad de mineral descubierto por las labores de mina, viene el Coto del Francisco. Fueron denunciadas estas minas, casi en su totalidad, por el Sr. Evaristo Colino; quien realizó en la llamada "Asunción" las primeras exploraciones en un afloramiento en el lecho de un pequeño arroyo que cruza la mina.

Más tarde y previas negociaciones, se constituyó en la Habana y bajo la presidencia del Sr. Regino Truffin, una compañía, que con el nombre de "The Francisco Mines," se hizo cargo de la exploración y explotación de las referidas denuncias, que más tarde adquirió en propiedad. Según puede verse en el plano que adjuntamos en la monografía, las labores de reconocimiento en dirección, llevadas a cabo en tres niveles diferentes, las menas se arrumban casi de oeste a este—condición muy favorable por lo que se explica al tratar de la geogenia de estos yacimientos en la referida monografía. Como resultado de aquellas labores, podemos decir que se pusieron al descubierto 100,000 toneladas de mena. La ley media del todo uno de esta mena se aprecia en un 3 por ciento en cobre, con mayor cantidad de plata, que cualquiera de las descubiertas hasta la fecha en aquella corrida mineral. En la actualidad se hallan paradas, contra lo que aconsejan las cotizaciones actuales del cobre.

A continuación debemos reseñar la mina Dora. Posee esta mina un amplio y extenso crestón de hierro. Por medio de las obras llevadas a cabo por debajo de este crestón se vino a poner de manifiesto una importante masa de sulfuro de cobre, que algunos hacen ascender a 100,000 toneladas, mientras que otros, las dejan reducidas a 40,000. Creemos que el justo apreciado, sin embargo se halla hacia el término medio, o sea hacia las 50,000. Lo mismo que la cantidad de mineral, ha sido la apreciación de la ley de todo uno objeto de diversas apreciaciones. La que estimamos más prudente, en vista de los caracteres macroscópicos que presenta la mena, es la que la señala el ingeniero Sr. Luis G. Lorenzana, quien la estima en un 4 por ciento en cobre.

Viene a continuación la Cándida, notable también por la riqueza de sus menas, y por el alto porcentaje de sus aguas vitriólicas. Comenzó a trabajarse allá por el año 1916, durando poco tiempo los trabajos, a causa de haber sobrevenido la guerrita de febrero. Sin embargo en el pequeño lapsus de tiempo que duró la explotación, se extrajeron y embarcaron por el puerto de Dimas unas 3,200 toneladas de sulfuro de cobre del 17½ por ciento en cobre. Llama poderosamente la atención por el color de las tierras que forman su montera, no dejando por eso de existir verdaderos crestones. Muchos dicen que el mineral de la Cándida se ha agotado; permítasenos disentir de tal opinión.

Debemos a continuación mencionar la mina Nuestra Señora de las Mercedes, situada en el Guayabo, Guane, y que en unión de las San José y Santa Romualda, forma el coto minero denominado "Río Frío." Esta mina tuvo dos períodos de exploración. Durante el primero, puede decirse se limita a explotar el afloramiento en el lecho del arroyo Guayabo, largo como 40 varas y ancho como 10, compuesto de hidrocarbonatos y sulfuros de cobre. En la segunda, se registra en primer término la parte alta del criadero y a base de los resultados obtenidos, se acometen las labores en profundidad. Como resultado, se obtiene el descubrimiento de una veta de 116 metros de longitud por 2.60 de potencia media, hallándose desviada por una falla hacia su extremo noroeste. Se localiza la presente veta a los 22 metros de profundidad y a una distancia del pozo próximo a 12 metros. La ley media del todo uno podrá oscilar entre el 3 y el 7 por ciento en cobre; se han encontrado especies muy puras de calcopirita, cuyo análisis llegó al 32 por ciento en cobre. Se halla totalmente inundada.

Sigue a esta la mina Celia Gregoria en asiento Viejo. El mineral de cobre extraído de esta mina, es una excelente calcopirita acompañada de cuarzo y pizarra, como gangas. Se realizaron aquí un buen número de labores, de las que las primeras descubrieron algunos cuerpos de mineral, sin obedecer a plan científico alguno en su realización. Más tarde y cambiada la dirección de la mina, se sujetó el plan de exploración a un método más científico y ordenado, dando por resultado el descubrimiento de nuevas e importantes masas de mena, cuya ley media en los todos unos, seguramente alcanzará un promedio del 6 por ciento. Quien desee enterarse más de los pormenores de esta mina, puede leer la monografía del cobre, donde insertamos un trabajo del entonces director de la misma, D. Manuel G. Lago. Hemos de añadir a esto, de nuestra propia cosecha, que durante la estancia en el cargo de la dirección de esta mina del tan amable como distinguido ingeniero que antes se cita, pudimos apreciar una existencia de mineral en esta mina no menor de 6,000 toneladas de mena de cobre de la ya citada ley.

Existen aparte de las minas hasta el presente reseñadas, y dentro de la que en trabajos publicados en los Boletines de minas de la República, numerados con los números 7 y 8 señalamos como cuarta corrida, otras minas al presente de menor importancia, por lo que al resultado de las labores en ellas realizadas, se han obtenido, en relación con las menas de cobre.

Entre estas, vamos a citar algunas de ellas: la Araceli, por ejemplo, posee un buen afloramiento, puesto de manifiesto por la labor de ahonde de su curso del arroyo Las Vacas, afluente del Río Frío, que lo es a su vez del Cuyaguateje.

La denuncia Santa Lucía o mina del Dr. Rubio, inmediata al pueblo de Guane. Esta denuncia presenta superficialmente, en el lecho del arroyo Zarzal, sulfuros de cobre (calcopirita cubierta en sus caras externas con una débil cutícula de óxido negro) y plomo (galena). Sin embargo, una galería lanzada a cortar estas manifestaciones a 30 metros bajo el nivel de este afloramiento, cortó por debajo del afloramiento una masa de pirita de hierro de una potencia de 14 pies. Este caso es uno de las frecuentes rarezas con que de vez en cuando nos obsequia la naturaleza. No debe haber desesperación sin embargo; bien puede ser que las cosas, más tarde o más temprano vuelvan a su ser, y sinó téngase en cuenta que como más adelante decimos, esta denuncia pudiera ser una importante reserva, para ser aprovechada en la fabricación de abonos químicos.

La Anaconda, muy próxima a ésta, ofrece un buen afloramiento de carbonatos el propio Río Frío. Esta como la Araceli, no han sido exploradas por labor alguna.

San Gumersindo, más conocida con el nombre de la mina de "El Mono" y "Las Nieves," al ser exploradas, acusaron presencia de materiales altamente descomponibles en contacto del aire atmosférico, singularmente Las Nieves, cuyo material arde expontáneamente en contacto del aire. Ambas tienen alguna ley en cobre. Las Nieves acusa hasta el 4 por ciento.

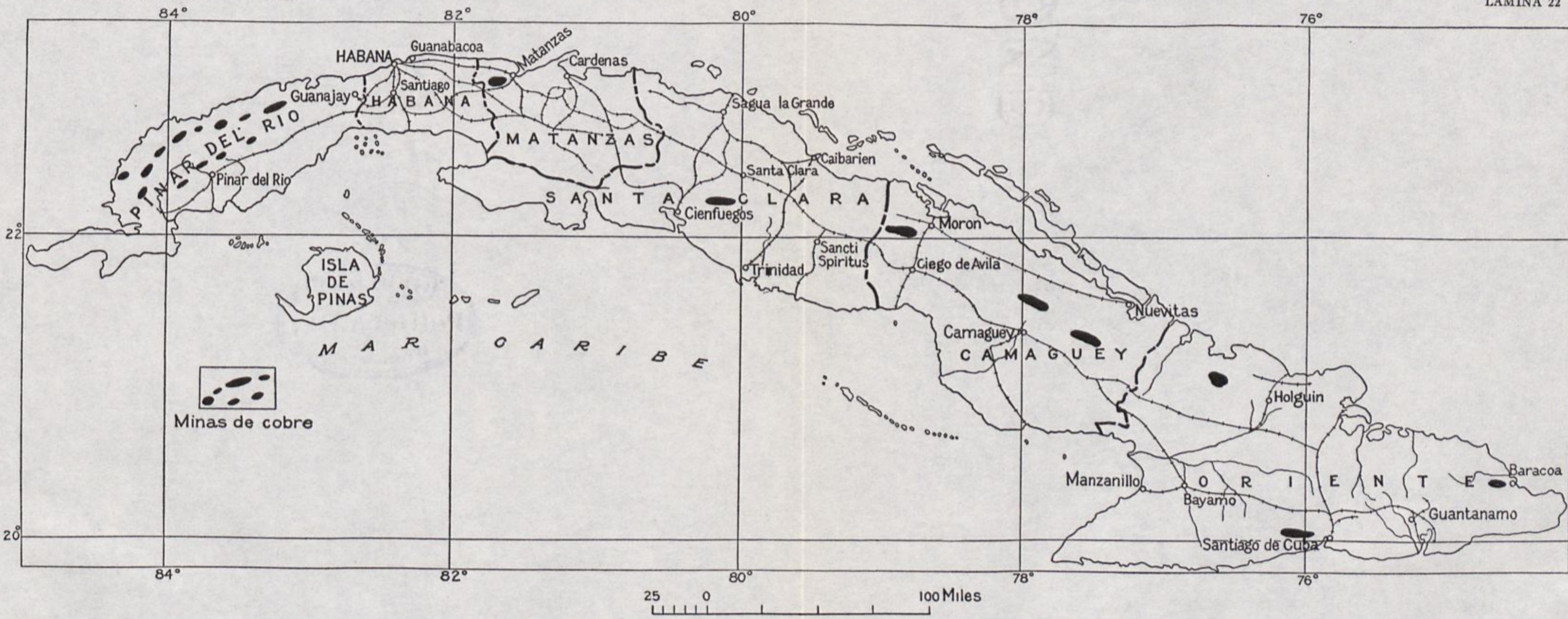
La Auro-Crupica, es otra denuncia a quien solamente su aspecto exterior la recomienda como prometedora. Las tierras de su parte alta acusan un 0.50 por ciento en cobre.

También presentan buenos caracteres exteriores, las Mejor y San Ramón, colindantes con la Cándida.

En cuanto a las minas de Malas Aguas, existe una leyenda de que fueron de antiguo conocidas y aún explotadas por los conquistadores. No sabemos a punto fijo lo que haya sobre el particular; lo cierto es que, de estas minas se extrajeron muestras, que se remitieron para su análisis a los Estados Unidos y que dieron un resultado aceptable en cobre.

Esto cuanto se refiere, a las minas localizadas en el eje del anticlinal de la provincia.

Por lo que se refiere a los yacimientos que se localizan en la corrida que pasa muy próxima a la ciudad de Pinar del Río, tenemos que decir, que hasta la fecha, la que mejor resultado ha dado en relación con las labores en ella realizadas, es la que con el título de "Isabel Rosa" se sitúa en barrio de San José, en el municipio del propio Pinar del Río. El Sr. MacNulty, último director que tuvo esta mina, nos clasifica la mena de esta mina como cubanita (variedad de calcopirita), cuya composición es según certificado de la casa Ledoux Co. la siguiente:



CROQUIS DE LA ISLA DE CUBA, MOSTRANDO GROSSO MODO LA REPARTICIÓN DEL COBRE EN LA REPÚBLICA

Cobre	por ciento..	16
Niquel	do....	9.21
Plata	onzas en tonelada..	2.50
Oro	do....	.01
Hierro	por ciento..	32.35
Azufre	do....	24.89

Señala dicho señor como dirección de la metalización la de oeste a este, fuertemente afectada por un sistema de fallas.

Nosotros creemos que con el análisis anteriormente apuntado, la denominación más apropiada a esta mena es la de pirrotina niquelífera. A pesar del análisis anteriormente apuntado, y en honor a la verdad, hemos de confesar, haber visto en esta mina una veta de calcopirita bastante pura.

Durante el año 1917 se escogieron y embarcaron de los minerales extraídos de esta mina 200 toneladas de las que produjeron un beneficio líquido de 5,090 pesos, moneda americana.

Por lo que respecta a la Cuprífera Pinareña y América, denuncias son que a la hora presente pueden encerrarse en una simple interrogación.

Hasta aquí, lo que respecta a los yacimientos de cobre, que podemos con algún motivo relacionar si no en todo, en parte, con las soluciones hidrotermales.

De las denuncias cuyos yacimientos conocen un origen de contacto heterogéneo, citaremos en primer término la Constancia, cuyos breves pormenores quedan expuestos al reseñar los primeros criaderos de esta provincia. Otra de las denuncias cuyo yacimiento, reconoce el mismo proceso genético es la mina Pollack, situada en el barrio de Damas a 10 kilómetros de Bahía Honda, del término municipal de Cabañas. Se disponen las masas de cobre de estas minas en el contacto de la caliza jurásica que forma las masas principales de los macizos de la región, con las serpentinas (peridotitas) que emergieron aquí a través de las fracturas y hundimientos. La ley de las menas encontradas es de un 12 por ciento, habiéndose embarcado durante la guerra mundial unas 60 toneladas de mineral de este tipo. La prematura muerte de su director Mr. Morse, entibió un tanto el ánimo de la compañía explotadora de este fundo, en el que, dado lo precario de sus labores han quedado sepultadas no menos de 2,000 toneladas.

La mina Concepción o de Mendieta, situada al sur del poblado de las Pozas, parece (interpretando lo que muestran sus escombreras), tratarse de un yacimiento de pirita ferro-cobriza, cuya ley en cobre será poco o menos de un 2½ por ciento. En la escombrera de la mina predomina el sulfuro de hierro. Esta mena lejos de despreciarse, sépase tiene un porvenir excelente, por sus relaciones con los abonos químicos. A juzgar por lo que la escombrera acusa, existen en la mina potentes cuerpos de sulfuro de hierro.

A parte de las minas citadas, existen un buen número de registros mineros en la República. Para darse uno cuento de la importancia de este metal en la misma, ha de saberse, que en la actualidad, pasan de 1,305 el número de títulos de propiedad concedidos por los presidentes de la República, y que aún faltan por conceder algunos más.

A continuación damos un plano de la República (lám. 22), en que se sitúan grosso modo la localización de sus principales yacimientos.

Copper in the West Indies and Central America[1]

By C. P. Ross

United States Geological Survey, Washington

Most of the known metalliferous deposits of any consequence in the West Indies and Central America, especially those of copper and iron, are in Cuba, although there are numerous mining concessions elsewhere. Cuba is unique in this region in that several of its copper mines at different times have been profitably worked on a considerable scale. Copper was mined even earlier on the island of Hispaniola and is known on other islands, but very little has been produced on any of them. In Central America, so far as I know, there are no copper mines, but certain of the auriferous lodes in Nicaragua and possibly elsewhere contain some copper, and a few practically undeveloped copper lodes are known.

Cuba

Summary

Copper deposits are known in districts spaced at short intervals from one end of Cuba to the other (1, 2). (See pl. 22.) In the early days mining appears to have been confined to the Cobre district, near Santiago. Active development here ceased in 1868. It was resumed by American companies after the Spanish-American war but without much success. Since 1530 copper has been successfully searched for in many other parts of the island, especially in Santa Clara, Matanzas, and Pinar del Rio Provinces. Pinar del Rio contains most of the lodes and the only ones at which active mining on a large scale has been done in recent years. As plate 22 shows, copper has been mined in 13 localities in this Province and in 8 localities in the rest of the island.

Most of the lodes are quartz veins with chalcopyrite and other sulphides and their oxidation products. Many of the veins cut diorite and other intrusives of Tertiary age. Some, as at El Cobre, are in lava and pyroclastic rocks, apparently of Cretaceous age (3, pp. 535–543). Near El Caney, apparently in the same volcanic formation, there is amygdaloidal basalt with the cavities filled with native copper. This variety of ore deposit appears as yet to have been little developed. Some of the lodes, including those recently productive in Pinar del Rio, are shear zones in supposedly pre-Jurassic argillaceous rocks containing chalcopyrite and pyrite (3, pp. 334–336).

The Cobre district, in which mining was extensive in the early days, and the recently active Matahambre mines are described in greater detail below. Regarding both these and the other copper deposits of Cuba little geologic information is available.

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[1] Published by permission of the Director, U. S. Geological Survey.

Cobre district

The Cobre district (1, pp. 40–51), the oldest and most extensively developed of the copper-mining regions on the island, is in the Province of Santiago de Cuba (Oriente), 7 miles west of Santiago and not far from the southeast coast of Cuba. The mines here were intermittently active for more than 200 years. Several of the shafts exceed 800 feet in depth. The workings, now almost entirely caved, were originally extensive, a wide hill having been undermined. The average annual production in the middle of the 19th century was about 25,000 tons. The ore mined contained 9 to 25 percent of copper. No estimates as to the total production are available.

The lodes occur in fragmental volcanic material interbedded with lava and grit and cut by dikes, near the base of a marine sedimentary series of probable Cretaceous age. The strata trend east and dip north, away from the crest of the Sierra Cobre, on whose flanks they lie. This mountain range is a portion of the Sierra Maestra.

The lode system trends somewhat north of east and locally stands nearly vertical but in general dips southward at moderate angles. Several veins have been traced for 3,000 to 5,000 feet, and locally many closely spaced but shorter veins fan out from the master fissures toward the southwest in horsetail fashion. Most of the production has come from an area about 800 yards long and 200 yards wide in which the horsetail veins are especially numerous. Several cross faults exist but apparently have not offset the ore bodies greatly.

Mineralization consisted in alteration of the country rock along the fissures and deposition of quartz masses. Chalcopyrite and pyrite were deposited both in the quartz and as lenses of more or less massive sulphide in the altered country rock. Some of the ore shoots were stoped for widths of 20 to 40 feet. At depth gypsum becomes abundant in the gangue. Pyritic dissemination and other alteration extended through the country rock far beyond the limits of commercial ore.

Oxidation was apparently complete to a depth of about 100 feet. Much of the early mining consisted in digging out the soft, oxidized material exposed at the surface.

Matahambre district

The Matahambre district (2, pp. 40–70; 4, pp. 2793–2794) is in Pinar del Rio, in the northwestern part of Cuba, about 100 miles west of Habana. Lodes in this Province were little known in the early days, but during the World War more copper prospecting was carried on here than in any other part of the Republic. Several lodes are now known, and one, discovered in 1913, has been extensively developed by Minas de Matahambre, S. A., a company affiliated with the American Metal Co. This mine has 20 levels, of which the three lowest are in the development stage and the rest are or have been in process of stoping. There are three shafts, one of which is 1,800 feet deep. The daily production in 1929 averaged about 1,000 tons of mine ore, running somewhat over 5 percent of copper. The ore reserves were about 1,000,000 tons.

The country rock comprises shale, shaly marl, and sandstone. The average strike is about N. 45° E. and the dip 45°–60° NW. The mineralized zone trends north and dips 45° E. Both the size and the grade of the ore bodies decrease northward. Numerous major faults divide the lode into ore bodies of different size. The faults trend about N. 60° E. and have a slight upthrow to the northwest. These data, taken from Allende's description (2, p. 43), imply that the lode originally lay transverse to the bedding and has since been cut up by faulting. In his discussion of genesis, however, Allende argues that the observed conditions might have been produced by ore deposition in the bulged portions of a previously crenulated series of beds, these relations being obscured by subsequent faulting. On this hypothesis the lode would be concordant with instead of transverse to the bedding.

The ore occurs in irregular masses and in veins, and interpretation of its geologic relationships is complicated by faulting and folding. Deposition is reported to have occurred mainly by fissure filling, but in part by replacement. Dissemination of sulphide has taken place where quartzose beds overlie the ore but not where shale forms the walls. The principal sulphides are chalcopyrite and pyrite, but locally there is some galena and sphalerite. Quartz is not abundant in the better ore shoots.

Hispaniola

The eastern two-thirds of the island of Hispaniola is occupied by the Dominican Republic and the western third by the Republic of Haiti. Both contain numerous prospects for different metals, including copper, but there has been very little production to date. The only places where any considerable exploration for copper has been undertaken are the San Cristobal and Hatillo districts, in the Dominican Republic, and the Terre-Neuve and Grande-Rivière du Nord districts, in Haiti.

The San Cristobal district (5) is in the Province of Santo Domingo about 15 kilometers from the south coast of the island and 20 kilometers west of Santo Domingo, the capital of the Republic. Lodes here have been prospected since 1847, but most of the development work was done in 1912 to 1917. During this period several small shipments of picked copper ore were made. Exploration is still in progress (4, p. 2795).

The country rock consists of altered tuff, breccias, and lavas, cut by a few small porphyritic dikes. The lodes comprise small slips on shear zones lined with quartz and metallic minerals. Numerous discontinuous mineralized slips are known on Búcaro and San Francisco Hills. One variety contains malachite with some quartz, hematite, and usually some sulphide in chloritized volcanic rock. Other veins contain somewhat oxidized chalcopyrite, pyrite, bornite, and specular hematite in quartz. Chalcocite occurs locally. The ore shipped is reported to have come mostly from Búcaro Hill. It was carefully sorted, about 10 tons being mined for each ton shipped. The copper in the shipments of which record is available ranged from 8.6 to 16.9 percent, and the gold and silver content was low. The average value was $57.70 a ton.

The prospect known as La Rama, opened in 1919, differs from those described above mainly in a higher gold content. Specular hematite is absent, and galena, not seen elsewhere, is sparingly present.

Near Hatillo, in the Province of La Vega, in the central part of the Dominican Republic, copper prospecting has been carried on intermittently for many years but little has been done recently, and apparently there was never any considerable production (5, p. 230). Slag with blebs of copper shows that some of the prospectors smelted a little of the ore. The principal workings are on a shear zone in crushed and sericitized chloritic schist in which there are quartz stringers and small amounts of oxidized iron and copper minerals.

Copper deposits in the Terre-Neuve district, near the Gulf of Gonaives, in northwestern Haiti, appear to have been known since the 17th century (6). They were intermittently developed on a small scale from 1898 to 1920 and are still held by the Haiti Mines Co. (4, p. 2793).

The two principal types of mineral deposits in the district are contact-metamorphic deposits in Tertiary limestone and fissure veins in Mesozoic volcanic strata and Miocene (?) intrusions. Both are probably genetically related to the Miocene (?) intrusions. The contact-metamorphic deposits contain principally iron and copper with a little lead and zinc. These deposits are confined to a zone trending northwestward and bordering the intrusions of quartz diorite and dacite porphyries. The zone is about 10 kilometers long, and its maximum width is 3 to 4 kilometers near Terre-Neuve village. Individual bodies reach 10 or 15 meters in width. Some are rudely tabular, but many are irregular. The principal minerals are garnets, epidote, chlorite, quartz, magnetite, hematite, and chalcopyrite. Oxidation and enrichment have been unimportant. The richer ore bodies probably do not average over 3 to 5 percent of copper, although richer samples have been obtained in places. The production has been small, and the outlook, even under favorable circumstances, is not encouraging.

The veins are widely scattered. Most are rather small, those as much as 40 centimeters wide being exceptional. Some contain pyrite, chalcopyrite, and specularite in a gangue of quartz and calcite. Others contain chalcopyrite, pyrite, sphalerite, and galena in a gangue of quartz and some barite. Both types carry some gold and silver. The second variety is more common and has been more oxidized and enriched than the first. Picked samples from enriched portions of narrow veins contain over 30 percent of copper, more than 50 ounces of silver to the ton, and a little gold, but most of the veins are of very low grade, many being mere quartz stringers with traces of sulphides and their oxidation products.

Another area in Haiti which has been much prospected for copper is near the town of Grande-Rivière du Nord, in the northeastern part of the Republic. Most of the small amount of development work here was done in 1902 to 1915. The veins are in altered volcanic rocks of middle Mesozoic age and in intrusive, probably late Cretaceous quartz diorite. They are genetically related to the diorite. The country rock is so much faulted and brecciated and the veins are so small that persistent lodes are not probable. The primary ore consists mainly of pyrite and chalcopyrite in quartz, with some calcite and specularite. The richer ore contains chalcocite, bornite, and covellite and evidently has resulted from enrichment. Although some masses of such material are rich, they are so small and scattered as to offer little promise of being of commercial value.

Puerto Rico

Puerto Rico contains several copper prospects but none that are much developed or, so far as known, of much promise. The principal localities are shown in figure 48. The following summary is based on accounts by Low (7) and by Colony and Meyerhoff (8).

There are several small openings south of Ciales and Morovis, in the north-central part of the island. The principal one of these is at Barrio Pasto, about 3 miles southwest of Morovis. About 60 tons of picked ore is reported to have been shipped from a breccia zone in late Cretaceous intrusive andesite porphyry, in which are limestone fragments that have also been mineralized. Ore deposition is thought by Colony and Meyerhoff to have been largely controlled by shrinkage cracks in the porphyry. The ore is a mixture of the common primary and secondary sulphides with some oxidation products in hydrothermally altered rock in which sericite, carbonate, chlorite, and albite were formed during mineralization. The mineralization was spotty, most of the workings being almost barren. Low estimates that in a few places the ore averages about 3 percent of copper and a little gold and silver.

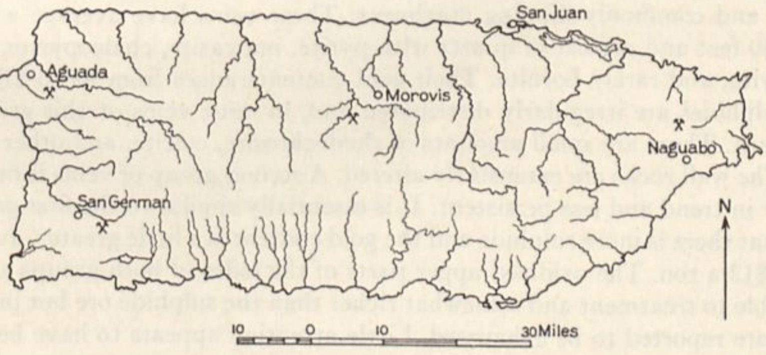

FIGURE 48.—Sketch map of Puerto Rico showing location of copper prospects. (After Bela Low.)

About 2 miles southeast of Aguada, near the west coast of the island, there has been a little development on a crushed zone in an andesitic flow containing native copper and malachite in veinlets nowhere more than a few inches wide.

Near San German, farther south, there is irregular mineralization in decomposed andesite porphyry. Malachite and chalcocite are present in places. The best showing (7) is in a tunnel where the ore averages $3\frac{3}{4}$ percent of copper for a width of 3 feet and a length of 30 feet. A shipment of about 200 tons of picked ore was made in 1918.

Near Naguabo, in the eastern part of the island, there are a few copper prospects. The largest one, long inaccessible, is reported to have been worked principally in 1866 to 1868, and copper smelted from its ore was shipped to Spain. Some work is reported to have been done here up to 1898. Float malachite ore of good grade occurs in a nearby ravine (7).

Jamaica

Copper has been found in 9 different localities in Jamaica (9). Development has been apparently confined to the Clarendon Hills, in the south-central part of the island, about 15 miles from the coast, whence small shipments have been made. The last development of record was in 1906 to about 1910 (10). There are several short tunnels a little over 1,100 feet in total length, which show small veins containing chalcopyrite, bornite, and chalcocite. The Copper Handbook regards them as of little promise (10). The deposits here have also been described by Outerbridge (11, 12), who was inclined to regard them favorably.

Nicaragua

The principal known ore deposits in Nicaragua (13, 14, 15) are in the northeastern part of the Republic, in the headwater basins of the Prinzapolca and Wanks Rivers. Gold was found here by early Spanish explorers, but active lode mining dates from about 1900. The gross production appears to have been about $14,000,000, mainly in gold.

The country rock is mainly Tertiary andesitic lava and intrusions related to it. One group of lodes comprises conspicuous and persistent veins trending N. 45° E. and commonly dipping northwest. These veins have average widths of 20 to 30 feet and consist of quartz with pyrite, marcasite, chalcopyrite, galena, sphalerite, and rarely bornite. Their gold content ranges from $3 to $10 a ton. The sulphides are irregularly distributed and, in most veins of this group, not abundant. There are small amounts of rhodochrosite, calcite, and other carbonates. The wall rocks are extensively altered. A second group of veins is much less regular in trend and less persistent. It is essentially similar to the first group except that there is more sulphide and the gold content is a little greater, averaging about $12 a ton. The oxidized upper parts of the lodes of both groups are more amenable to treatment and somewhat richer than the sulphide ore but in several mines are reported to be exhausted. Little attention appears to have been paid to the base metals in these veins.

Several copper deposits, both disseminated deposits and veins, are known. The only one yet developed, so far as the records show, is the Rosita, on the Banbano River, which was worked by the Tonopah Mining Co. in 1917 and 1918. This deposit consists of disseminated pyrite and chalcopyrite with some gold in an andesitic intrusion which forms a steep mound several hundred feet high. There is a thoroughly oxidized zone at the surface, underlain by a zone of enrichment in which the copper content is as much as 10 percent, and the deposit contains enough gold to have been formerly worked for this metal alone. Churn drilling is reported to have developed 1,250,000 tons of 5 percent copper ore.

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[NOTE.—The index to the whole work will be found at the end of volume 2.]