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Bosquejo geológico

Rocas del basamento cristalino

Región central y noroeste.—Las rocas del basamento cristalino forman los relieves de las sierras en las provincias de Córdoba, San Luis, La Rioja, Catamarca y Tucumán, hacia el oeste avanzan también en San Juan y más al norte en el borde de la Puna, en Salta y Jujuy y en plena Puna en el Territorio de Los Andes. En la gran área central predominan los gneises y micacitas; en el norte y noroeste las filitas, cuarcitas y esquistos arcillosos. A estas rocas se asocian principalmente en el centro, intercalaciones de calizas y anfibolitas, diques de gabbros y dioritas y grandes intrusiones de granitita con sus pegmatitas.

Mineralización relacionada con ellas: Wolframita, casiterita, oro y algunas pequeñas segregaciones magmáticas de cobre.

Región oriental.—Entre el centro y la costa sudeste de la provincia de Buenos Aires afloran las rocas cristalinas en pequeñas áreas en las sierritas de Olavarría, Tandil y Balcarce; también en la parte sur de la sierra de la Ventana. Son esquistos cuarcíticos y filíticos y gneis con grandes cuerpos de dioritas y granitos milonitizados. Su mineralización es nula.

Región patagónica.—Desde el centro del territorio nacional del Neuquén hacia el sur, llegando al través de Río Negro hasta el norte del territorio del Chubut, aflora también el basamento cristalino con componentes litológicos semejantes a los de la región central.

Sedimentos paleozoicos

Los terrenos sedimentarios paleozoicos cubren las rocas cristalinas en la faja preandina llamada "Precordillera de San Juan y Mendoza," que se prolonga al norte hasta el borde oriental de la Puna por las provincias de Salta y Jujuy, mientras que por el sur se desvía hacia el este perdiéndose, aunque parece tener una continuación en la sierra de la Ventana y el nordeste de Patagonia. Son rocas esquistosas, plegadas y dislocadas (metamorfismo débil; orogenia pérmica). Contienen intrusiones subsecuentes de dioritas cuarcíferas, granititas y pórfidos cuarcíferos. Quedan insignificantes restos de las series superiores de esta cubierta, con *Glossopteris*, en el sudeste de La Rioja, San Luis y Córdoba.

Geosinclinal andino

El geosinclinal andino es una unidad geológica muy característica. Consta de sedimentos marinos desde la cordillera de San Juan hasta el sur del Neuquén; más abajo ellos están interrumpidos por una supresión más o menos completa entre los paralelos 41° y 43°, y de allí se continúan hasta Tierra del Fuego. Un ensanchamiento de la cubeta hacia el este en forma de gran bahía ocupó todo el Neuquén entre los ríos Colorado y Limay.

Potentes masas eruptivas (espesores hasta cerca de 5,000 metros) se intercalan en el Jurásico y Cretáceo en Mendoza y Neuquén, sobre la frontera chilena, y en la cordillera patagónica. Mineralización, muy escasa y poco conocida.

Intrusiones granodioríticas andinas

Las intrusiones granodioríticas andinas están alojadas preferentemente en los estratos mesozoicos del geosinclinal andino y en las series de porfiritas intercaladas entre sedimentos del Jurásico y Cretáceo de la cordillera occidental chilena. Pasan al lado argentino al sur del río Diamante (Mendoza), donde afloran de tanto en tanto cerca del límite. Estas rocas tienen cierta importancia como portadoras de minerales de cobre, plomo y oro.

Los distritos cupríferos

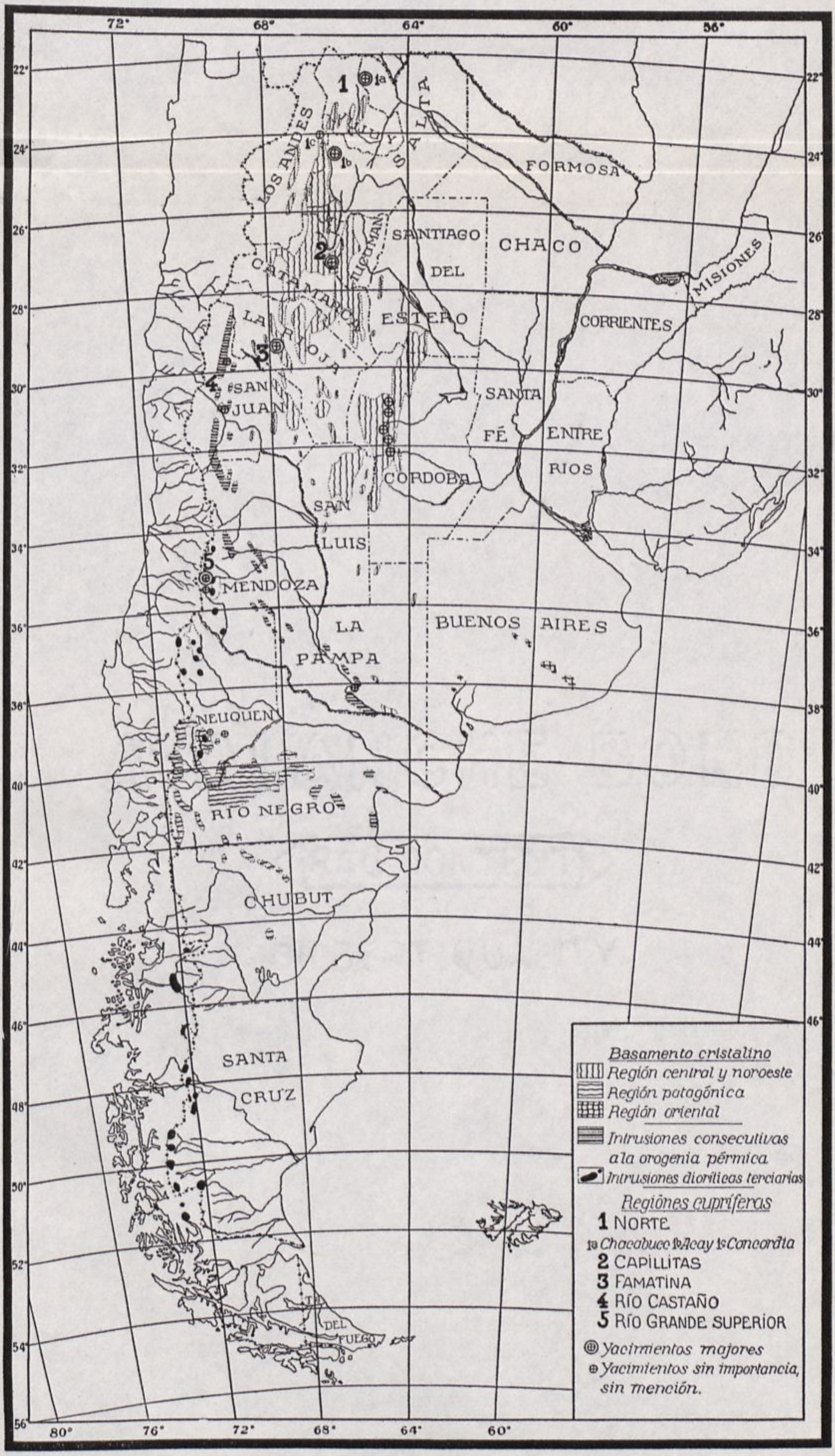
Región cuprífera del norte (véase lám. 23, no. 1).—La mineralización de la región cuprífera del norte está ligada a andesitas y dacitas terciarias. Los filones metalíferos parecen contener generalmente calcopirita con galena, blenda y antimonita en profundidad y predominio de los minerales de cobre en los niveles superiores. Ejemplos:

1a. Chacabuco: Mineral en fallas transversales que cortan una estructura imbricada de rumbo norte-sur que afecta pizarras proterozoicas, cuarcitas cámbricas y esquistos margosos ordovicianos. Los estratos están cortados por filones lamprofíricos y andesita hornblendífera. Los minerales contenidos en las fallas son calcosina, bornita, azurita y malaquita, seguidos inferiormente por galena, calcopirita y pirita.

1b. Nevado de Acay: Minerales en pizarras proterozoicas ligados a rocas andesíticas; contienen sulfuros con cobre, hierro y plomo.

1c. Concordia (a más de 4,000 metros): Consta de esquistos proterozoicos atravesados por numerosos filones de dacitas y otras rocas andesíticas, en gran parte cubiertas por aglomerados volcánicos y las tobas correspondientes. Además de minerales de plomo contienen tetraedrita y otros sulfuros con crisocola.

Región de Capillitas (*Catamarca*) (lám. 23, no. 2).—La región de Capillitas contiene yacimientos en granito probablemente paleozoico atravesado por liparita del Terciario superior. Los minerales se hallan en la roca volcánica y fuera de ella en las fracturas que dividen el granito en varias direcciones. Los minerales principales son calcosina, bornita, calcopirita, enargita, tetraedrita y pirita, más abundante en profundidad. En los antiguos trabajos de las zonas de oxidación



CARTA DE LA REPÚBLICA ARGENTINA MOSTRANDO LAS UNIDADES GEOLÓGICAS Y SUS RESERVAS DE COBRE

se explotaba principalmente el oro y la plata, ahora mucho más escasos en los sulfuros primarios.

Región de Famatina (*La Rioja*) (lám. 23, no. 3).—En la región de Famatina, en el cuerpo de la montaña (4,000 metros) de esquistos arcillosos y silíceos, principalmente silúricos, corren numerosos filones de rocas dacíticas dispersos en una superficie extensa. En ellos se abrieron numerosas minas en la segunda mitad del siglo pasado, explotándose los enriquecimientos de plata y oro superiores. Los minerales principales son calcopirita, enargita, bornita, famatinita, proustita, pirargirita, argentita, pirita, mispickel, etc.

Región del Río Castaño (*San Juan*) (lám. 23, no. 4).—En la región del Río Castaño, como en la región de Famatina, el substratum es paleozoico, con sus correspondientes intrusiones de diorita cuarcífera y granitita, cortado por penetraciones de pórfido granítico permotriásico y de rocas dacíticas terciarias que forman vetas y mantos de tobas. En su mineralización no es tan notable como en Famatina el predominio de los sulfuros cupríferos, habiéndose explotado principalmente oro y plata.

Región del Río Grande superior (*Mendoza*) (lám. 23, no. 5).—El cuerpo montañoso en la región del Río Grande superior se compone de calizas del Dogger superior, yeso, areniscas grises del Malm, conglomerado y calizas eocretáceas, cubiertas por brechas y gruesos mantos de labrador porfirita. Fué penetrado al principio del Terciario por diorita cuarcífera con su séquito de andesitas y dacitas. Aun cuando se han supuesto relaciones genéticas con las porfiritas, la mineralización debe atribuirse a la serie diorítica. Contiene calcosina, calcopirita y escasamente pirita, galena y blenda.

Reseña histórica

Algunas referencias sobre las actividades de las principales minas de cobre argentinas proporcionan los datos siguientes:

Mina Concordia.—La mina Concordia fué trabajada en tiempo del coloniaje español con el nombre de "Mina del Rey." Los minerales explotados eran de cobre, plata y oro. Hasta una profundidad de 25 metros existía tetraedrita, calcopirita y bornita con algo de galena y blenda.

En 1891 se formó la "Concordia Consolidated Mines Co." Esta empresa encontró cerca de 600 metros lineales de trabajos anteriores. Durante los primeros años la compañía realizó trabajos de exploración; las dificultades, entre las cuales están la situación alta y lejana de la mina y la irregularidad del yacimiento, hicieron que la compañía no pudiera continuar los trabajos desde 1897.

Otra empresa digna de mención fué la Compañía Minera La Concordia, que inició sus trabajos en 1905 con bastante impulso. Profundizó los pozos hasta 130 metros; además instaló una usina de fuerza eléctrica y otra de concentración de los minerales. Estas labores duraron cerca de 10 años.

Capillitas.—En Capillitas, aparte de los antiguos laboreos en las zonas de oxidación y de cementación, que dieron principalmente mucha plata y oro obtenidos por métodos metalúrgicos más o menos primitivos, se debe mencionar la explotación de la "Capillitas Copper Co.," con un capital de £600,000, que ocupó todos los filones y las antiguas fundiciones. Luego procedió a instalar una nueva fundición en Muschaca y un cable-carril de 25 kilómetros, el cual no funcionó satisfactoriamente. En 1907 pudieron ser tratadas en 7 meses 7,500 toneladas de mineral y los trabajos se suspendieron.

En 1909 la empresa fué adquirida por la "Capillitas Consolidated Mines" (capital £600,000). La cantidad de mineral extraída al renovarse por varios años las actividades fué estimada en más de 100,000 toneladas. En los años 1913 y 1914 las labores fueron muy reducidas, y esta situación se prolongó a consecuencia de la conflagración mundial. Después sólo se realizaron pequeños trabajos, pudiéndose citar también ensayos metalúrgicos efectuados por el Ministerio de Guerra. Recién en 1927 la firma Hochschild y Cía tomó la dirección de los trabajos más importantes, que a su vez sufren la paralización motivada por las condiciones económicas actuales.

Famatina.—Famatina es un centro minero célebre cuya historia abarca un par de siglos de laboreo. El interés de las explotaciones radicaba antiguamente en la riqueza en plata y oro, sobre todo porque se trabajaba en las zonas de oxidación; el cobre era hasta cierto punto un subproducto.

En 1895 se construyeron hornos de fundición en Patayaco y en 1890 en Santa Florentina. Por ese tiempo el Gobierno Nacional cooperó con la prolongación del ferrocarril hasta el vecino pueblo de Chilecito y con la construcción del cable-carril hasta la mina La Mejicana, de 34 kilómetros, terminado en 1907. (Véase lám. 24, *A*.) En 1902 se formó la "Famatina Development Corporation," con un capital de £400,000, y su filial "The Forastera Mines Co.," que adquirió y modernizó la fundición de Santa Florentina. Sucesivos aumentos de capital permitieron ampliar los trabajos e instalaciones. En 1908 el cable-carril transportó 20,000 toneladas de mineral que dieron 2,574 toneladas de matas de fusión con 18 a 20 por ciento de cobre.

En 1912 se organizó "The Famatina Co." con un capital nominal de £800,000, la cual llevó a cabo importantes mejoras en la usina de fundición. En el año 1913 el mineral bruto fundido en Santa Florentina dió 2.56 a 7.85 por ciento de cobre, 1.93 a 10.92 onzas de plata y 0.163 a 0.457 onza de oro por tonelada. Inconvenientes técnicos y económicos motivaron la paralización de la compañía después de estos trabajos.

Otras dos empresas mineras habían comenzado explotaciones en menor escala en 1905 y tuvieron que desistir en 1908 y 1911 respectivamente.

Río Castaño.—En la región del Río Castaño se hicieron varios ensayos de explotación desde el año 1860. Tuvieron corta duración aun los más formales, que se dedicaron preferentemente al oro.

Río Grande superior.—Los yacimientos a lo largo del Río Grande superior fueron descubiertos en 1885. El mineral se llevaba en mulas a Chile. En 1901 se formó la "Mines Exploration Co.," empresa anglo-chilena con £200,000 de capital, figurando en su programa la construcción de un ferrocarril que llegase a las minas desde el valle longitudinal de Chile. La escasez de los recursos y capacidad industrial, además de las condiciones desfavorables del clina (sobre 3,000 metros) hicieron fracasar la empresa después del verano de 1906, en el cual alcanzó a extraer 2,500 toneladas de mineral con 20 a 25 por ciento de cobre.

A. FAMATINA, REPÚBLICA ARGENTINA. CERRO LA MEJICANA, DONDE SE ENCUENTRA EL GRUPO TERMINAL DE MINAS SERVIDAS POR EL CABLECARRIL.

Vista desde la estación 8. Longitud de la línea 34,670 metros. Desnivel 3,510 metros. Fuerza hidromotriz, turbinas de 400 hp. En 1908 transportó 19,376 toneladas de mineral a la fundición de Santa Florentina. Actualmente se mantiene en estado de funcionar.

B. VIEW LOOKING NORTH FROM CERRO COROCORO, BOLIVIA, UP THE VALLEY OF THE COROCORO RIVER.

The Vetas Ridge on the left. The Ramos Hills on the right. The Corocoro fault follows the valley along the base of the east slope of the Vetas Ridge.

Sobre esta base se formó la compañía "Burrero de Valle Hermoso," con 300,000 pesos chilenos de capital, la cual tampoco pudo subsistir, lo mismo que algunos otros ensayos de explotación siguientes.

Estadística

Producción de minerales de cobre en la República Argentina

Año	Kilogramos	Procedencia principal
1910	4,122,240	Famatina
1911	1,806,320	Famatina, Mendoza
1912	452,760	Famatina, Mendoza
1915	12,580	San Juan
1916	2,940	Famatina, San Juan
1917	44,160	San Juan, Mendoza
1918	551,410	Famatina
1919	191,460	Famatina
1920	320,700	Famatina, Mendoza
1921	1,271,000	Famatina, Capillitas
1922	773,000	Mendoza
1923	1,133,200	Famatina, Mendoza, Capillitas
1924	450,640	Capillitas, Mendoza
1925	399,720	Capillitas
1926	361,150	Capillitas
1927	268,120	Capillitas, Famatina
1929	147,530	Capillitas
1930	166,300	Capillitas
1931	31,500	Capillitas
1932	30,500	Capillitas

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The Corocoro copper district, Bolivia

By Joseph T. Singewald, Jr.
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Introduction

Location.—The city of Corocoro is the capital of the Province of Pacayes, of the Department of La Paz, Bolivia. Its population is about 10,000, almost exclusively Indian. It is situated on the altiplanicie, or high plateau of Bolivia, in one of the numerous groups of low hills that rise above the level of the plain. Its altitude is about 4,000 meters. The houses are strung out along the valley of the Rio Corocoro and several small valleys and gulches at the foot of the north slope of the Cerro Corocoro. The productive mines are in the immediate vicinity of the city.

Climate.—Because of the high altitude of the district radiation is rapid. The nights are always cold, and during most of the year ice forms. The days of sunshine are delightfully warm, but violent windstorms, often accompanied by snow or sleet squalls, occur in the afternoons. Though light snows or rains are frequent in summer, the climate is semiarid. Owing to the dryness of the climate and the nature of the surficial geologic formations, the district is almost devoid of vegetation and presents a bleak and desolate aspect. The discomforts experienced in living there are due mainly, however, to the lack of fuel and modern habitations.

Topography.—The district lies in a group of hills bounded on the north and west by the Pontezuelo River and on the south by the Cerro Corocoro. The valley of the Rio Corocoro, which has its source immediately north of the Libertad mine (fig. 49), is flanked on the west side by a ridge that slopes off steeply toward the Rio Corocoro and more gently to the Pontezuelo River, which parallels it about 2 kilometers to the west. The height of the ridge is about 120 to 160 meters. On the east side of the valley is a group of irregular hills rising to about the same height (pl. 24, *B*). The Corocoro Valley is terminated on the south by the Cerro Corocoro, which has a height of about 210 meters and which diverts the Rio Corocoro to the east (fig. 49).

History.—Upon the arrival of the Spaniards early in the 16th century they found the Indians working the oxidized outcrops of the ore bodies as a source of copper pigments. The oxidized ores were mined and smelted during the colonial period to furnish copper for the Potosi mint. Operations ceased with the revolution in 1781.

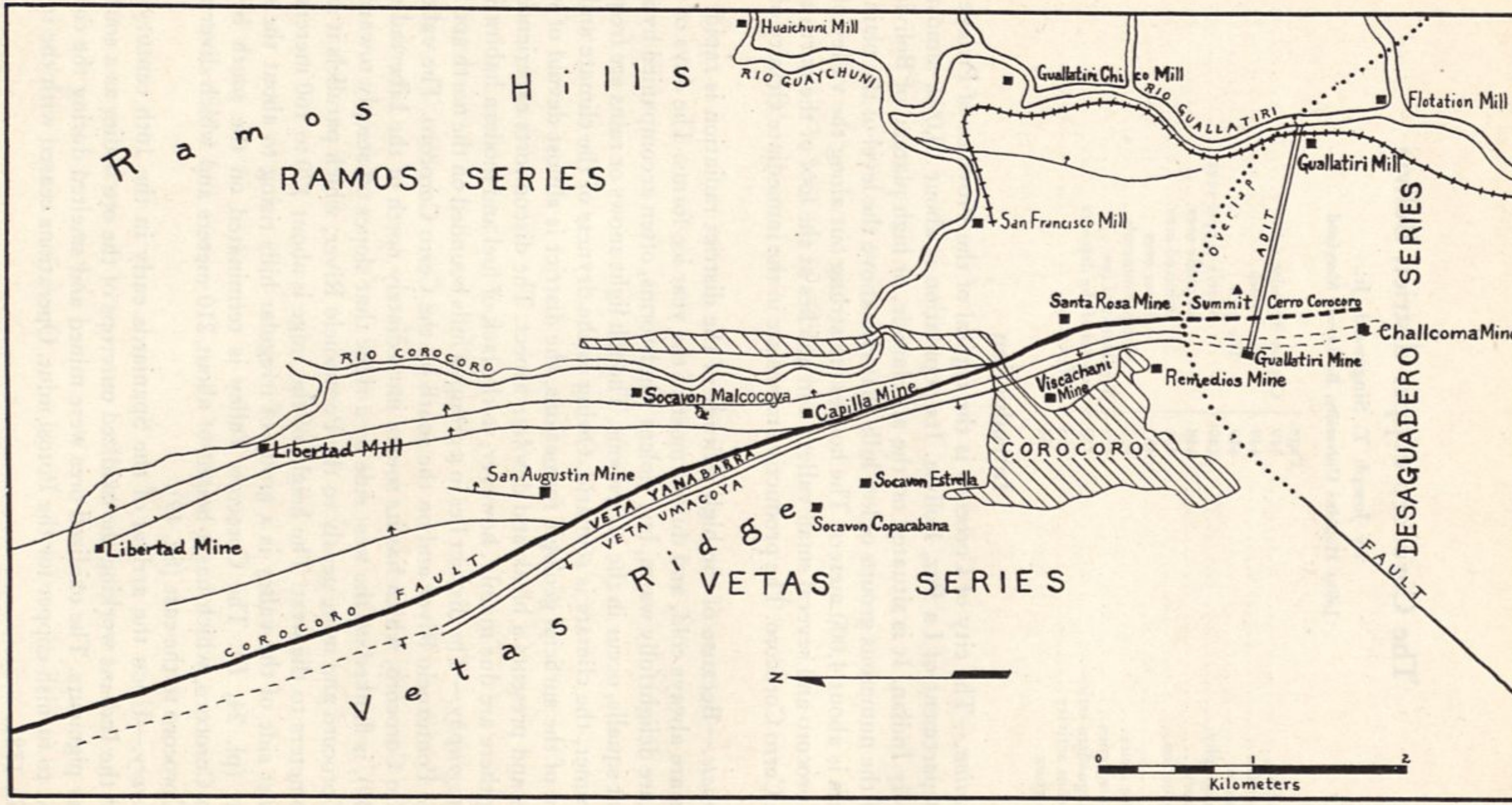

FIGURE 49.—Map of Corocoro district, Bolivia. (By J. T. Singewald, Jr.)

A second period of mining was begun in 1830 with the working of the native copper ores and continued actively until 1912. The diversified ownerships of the mines were gradually consolidated into two strong companies. The Compañía Corocoro de Bolivia, a Chilean company, was organized in 1873; and the Corocoro United Copper Mines, Ltd., an Anglo-French company, in 1909. During this period the annual production rose to as much as 4,000 tons of copper.

A new era opened with the completion of the Arica-La Paz Railroad and the branch from Tarejra to Corocoro in 1912, providing the district with railroad transportation and greatly reduced freight charges to the coast. From 1830 to 1912 the native-metal ores were almost the sole object of attention, and only native copper barilla (concentrate) running 85 percent of copper was shipped. In 1912 the output suddenly increased through the shipment of hand-picked sulphide and oxide ores averaging 18 to 25 percent of copper. In 1918 and 1919 the two companies installed flotation plants, and the Corocoro United Copper Mines a small leaching plant to treat the oxidized ores. The sulphide ores that were milled averaged 6 to 8 percent of copper, whereas the native-copper ores averaged at that time a little over 2 percent. By 1923 the output of sulphide ores began to decrease and the native-copper ores were again more actively worked. Production from 1919 to 1923 averaged over 10,000 long tons of copper annually. From 1924 to 1929 an average of over 8,000 long tons was maintained. Since 1929 the output has decreased rapidly. The Compañía Corocoro de Bolivia suspended operations in 1923, leaving the Corocoro United Copper Mines, Ltd., the only operator in the district. The properties of the two companies have been combined and are now being operated by the American Smelting & Refining Co.

Production.—The Corocoro United Copper Mines, Ltd., has furnished the following production figures, in long tons: 1927, 6,958; 1928, 6,534; 1929, 4,528; 1930, 1,654; 1931, 1,195.

Geology

The main geologic features of the district are relatively simple. There are two series of rocks that strike west of north and dip in opposite directions away from a fault that runs parallel to the valley of the Rio Corocoro north of the city and lies on the west side of the valley. Both series are prevailingly red and are made up of a thick sequence of shales, sandstones, and conglomerates, some of which may be more accurately called "tuffites" and "tuffs." The series of westward-dipping rocks contains more coarse clastic beds than the series of eastward-dipping rocks. Numerous beds of both series are impregnated with copper ores.

The copper-bearing beds of the westward-dipping series are called "vetas" and those of the eastward-dipping beds "ramos," and for convenience these names have become attached to the rocks themselves.

The Corocoro fault and the Vetas and Ramos beds extend southward into the Cerro Corocoro. Capping this hill and extending to the south and southwest is a third series of rocks, the Desaguadero series. They are also red and are lithologically similar to the Ramos. They unconformably overlie the Corocoro fault and the Ramos and Vetas series and are devoid of copper minerals.

No igneous rocks crop out in the Corocoro district. The nearest outcrops of igneous rock are at Cerro Chukapaca, 15 kilometers west of Corocoro, and at Cerro de Comanche, at Mirikiri, 20 kilometers to the north. The Chukapaca rock is rhyolite porphyry, and the Comanche rock is hornblende diorite porphyry.

Vetas series

A section of the Vetas series from the Corocoro fault, 2 kilometers north of Corocoro, westward to the Pontezuelo River has a thickness of 1,491 meters. This does not include the beds cut off by the fault nor the beds in and beyond the Pontezuelo Valley. In this section shales constitute 52.7 percent of the beds, sandstones 24.6 percent, and coarse clastic rocks 22.7 percent. Another section measured from the Corocoro fault along the Pontezuelo River 5 kilometers northwest of Corocoro, which includes neither the top nor the bottom of the series, has a thickness of 1,058 meters. This section, representing the middle half of the series, contains 38 percent of shale, 57 percent of sandstone, and 5 percent of coarse clastic beds.

The shales are almost invariably red. Much of the sandstone is also red, but its prevailing color is gray, and the coarse clastic beds are also gray. All the copper-stained zones are in sandy beds, and they are found over a stratigraphic range of more than 1,000 meters from the Corocoro fault. Many of the copper-stained beds also contain plant remains.

The grains and pebbles of the coarser rocks consist of sandstone, quartzite, shale, and fragments of igneous rocks, most commonly of hornblende diorite porphyry like the rock at Mirikiri. Where the fragments of igneous rock are abundant, they are angular and little water-worn, representing slightly water-sorted tuffs or possibly even true tuffs. The fragments of sedimentary rocks are as a rule fairly well rounded and water-worn. Associated with the quartz grains are subangular grains of feldspar, usually plagioclase, some undergoing kaolinization, others fresh and glassy. The matrix of the sandstones is more feldspathic and includes considerable chlorite.

Representatives of 23 species of plants have been collected from the plant-bearing layers of the Vetas. There was no change in the flora during the interval of sedimentation, and this corroborates the lithologic evidence that the sediments are of continental origin and were accumulated rapidly. The flora indicates a much lower altitude, not more than 2,000 meters, and a greater rainfall than at present. The age of the flora is Pliocene.

Ramos series

A section of the Ramos series measured from the Corocoro fault at the Libertad mine has a thickness of 3,736 meters. It does not include the beds cut off by the fault nor overlying beds beyond the measured section. In this section are 81 percent of shales, 18.7 percent of sandstones, and 0.3 percent of conglomerates. The shales are prevailingly light red to dark red. Some layers are brown, and thin intercalations of green shale are abundant. The sandstones show the same range in color as the shales, except that near the fault there are several beds of gray sandstone similar to those of the Vetas.

Cupriferous beds extend through 1,700 meters of the section nearest the Corocoro fault but differ from those of the Vetas series in that none of them are plant-bearing and most of them are in shale. In the measured section 14 cupriferous beds are in shale, 4 in sandstone, and 2 in gypsum.

The sandy beds show evidence of tuffaceous material like that in the sandy beds of the Vetas. Gypsum, which occurs only sparingly in the Vetas, is abundant in the Ramos beds. It occurs as beds, impregnations, and veinlets and stringers throughout the rocks.

It has generally been assumed that the Ramos beds are younger than the Vetas, but the evidence is not very definite. The only direct paleontologic evidence of the age of the Ramos series is furnished by the skeleton of *Macrauchenia boliviensis* described by Huxley and found in the Santa Rosa mine. This genus of the South American mammalian order Litopterna is confined to the Pliocene and Pleistocene. The Ramos shales in many places show mud-cracked surfaces and cylindrical, imbricatedly marked casts of what seem to be burrows of some organism. Such markings are also found in the Desaguadero series, serving to suggest the same general age for the two series of beds. The probability is, therefore, that the Ramos are younger than the Vetas, being late Pliocene or possibly even Pleistocene.

Desaguadero series

The Desaguadero series differs from the Vetas series in that the coarse clastic sediments so prominent in the Vetas are nearly lacking and from the Ramos series in the absence of gypsum beds and stringers. It is like the Ramos in the dominance of red beds and the fine grain of the sandstones. It differs from both series in lacking copper minerals.

The strike of the Desaguadero series across the strike of both Ramos and Vetas series and the Corocoro fault and the lack of mineralization prove that these beds are younger than both the other series, than the Corocoro fault, and than the mineralization. Southwest of Corocoro the Desaguadero series is faulted down against the Vetas series.

In a small quarry 3 kilometers southwest of Corocoro was found the footprint of an edentate or sloth, possibly related to some such form as *Priodontes*. This cannot be older than Pliocene and may be Pleistocene. The Desaguadero series has yielded no other paleontologic evidence of its age.

Igneous activity

The inclusion of fragments of rock identical in character witih the Mirikiri rock and various kinds of fresh volcanic rocks in the Vetas series proves that igneous activity had commenced in the region prior to the deposition of the oldest exposed Corocoro sediments and that, in part at least, the fragments were derived from rocks originating from the same magma as the Mirikiri rock. On the other hand, the Mirikiri rock seems to be intrusive into the red rocks of the Corocoro region. Hence the general period of igneous activity seems to have been more or less coincident with that of the deposition of these rocks and therefore coincident with the late Tertiary period of igneous activity of the eastern Andes.

Structure

The Corocoro fault is followed in the mine workings in Cerro Corocoro about 1 kilometer beneath the Desaguadero series. North of Corocoro it can be readily followed on the surface on the west side of the valley of the Rio Corocoro to the Libertad mine and for a long distance beyond. The strike of the fault is about N. 20° W. and is parallel to the strike of the Vetas series as shown by two of the principal ore beds, the Veta Yanabarra and the Veta Umacoya (fig. 49). On the other hand, the divergence of the Ramos in a more northerly strike and the emergence of successively lower beds northward is shown by the mapping of several prominent ledges of the Ramos series in the Corocoro Valley. Between Corocoro and the Libertad mine, a distance of not quite 3 kilometers, 406 meters of Ramos beds have come to the surface in that way.

The Vetas and the Ramos show considerable local variations in dip, but the average dip of the Vetas is between 55° and 60° W., and that of the Ramos between 45° and 50° E. Three exposures of the fault plane in the Corocoro Valley show a dip of 72° W. In the mines the fault has a steep westerly to nearly vertical dip. Hence the fault has a westerly dip that is greater than the normal westerly dip of the Vetas. With respect to the direction of movement along the fault plane the evidence is not unequivocal, some exposures indicating that the Vetas beds have been pushed over the Ramos, others that the Vetas have slipped down over the Ramos.

Copper deposits

Corocoro is the richest of a series of similar copper deposits that extend across the Bolivian high plateau from Lake Titicaca to the Chilean border and beyond into the province of Antofagasta as far as San Bartolo.

The principal mines of the Corocoro district stretch along the Corocoro fault for a little more than 4 kilometers, extending from the Challcoma mine, 1 kilometer south of the city, to the Libertad mine, 3 kilometers north of the city. With the exception of the Libertad mine, the shaft of which is 0.5 kilometer east of the fault, all the mines are close to the Corocoro fault.

Ore bodies

Mineralization has occurred mainly in beds of the Vetas series and the Ramos series close to the fault, but also to a minor extent in the fault itself. Workable ore has been deposited principally in arenaceous and pebbly beds, and only in the Ramos locally in shales. The Vetas beds have been much more productive than the Ramos, probably owing to their more favorable lithologic character.

The output of the Corocoro United Copper Mines has been derived chiefly from four mines on the Cerro Corocoro—the Challcoma, the Guallatiri Grande, the Santa Rosa, and the Viscachani. This company also worked the Estrella and Copacabana mines, in the Vetas ridge north of the town. The principal mines of the Compañía Corocoro de Bolivia were the Remedios, on the north slope of the Cerro Corocoro, and the Capilla, San Agustin, and Malcocoya, on the Vetas ridge and in the valley north of the town.

Two prominent ore beds in the Vetas series, the Yanabarra and the Umacoya, parallel the Corocoro fault and can be traced on the surface by outcrops and old workings. In the mines there are other workable vetas. No equally prominent Ramos ore beds crop out, although some of the beds exposed between the Libertad mine and the fault yield workable ore underground. A great many Vetas and Ramos beds have been worked at various times during the history of the district, and apparently at different times different names have been applied, especially in different mines, to the same ore bed. It seems that more ramos have been productive than vetas; but the vetas average greater width and richer mineralization, so that the names of the vetas are better known than the names of the ramos. The width of the ore bodies ranges from a few centimeters to 8 meters, but the average width is about 2 to 3 meters.

The ores

The copper in the Corocoro ores occurs predominantly as native copper. Less abundant are copper sulphides, with which are associated small amounts of arsenides. Still less abundant are oxidized ores. A small amount of native silver was encountered years ago.

Native-copper ores.—The typical native-copper ore of this district consists of nearly white to light-green sandstone irregularly mottled with specks of copper. The sandstone is made up of rounded to subangular grains of quartz and a little plagioclase feldspar, ranging from 0.15 to 0.60 millimeter in diameter and averaging 0.3 millimeter. The matrix consists chiefly of feldspar, chlorite, and a little calcite. The native copper has chiefly replaced the matrix, penetrating the quartz grains to a very slight extent. It occurs in grains and flakes ranging from 0.1 to 0.3 millimeter in diameter and averaging 0.15 millimeter. In some places the copper is regularly distributed through the rock; in others it occurs in small streaks and patches, between which the sandstone is nearly barren. The copper grains tend to aggregate to small knotty concretions that range from 0.5 to 5 millimeters in diameter.

The run of mine ores have averaged 2.5 to 3.5 percent of copper, but unusually rich ores carry as much as 15 percent. The copper content is said to decrease with increasing depth and in the lowest mine workings to be less than 2 percent or even as low as 1 percent. Rich ore is called "tacana," and if the particles of native copper are coarse it receives the name "chafra." In very rich ore the copper particles coalesce and isolate the sand grains to such an extent that the ore is soft and tough. Platy and arborescent forms of copper, abundant as fillings of joints, cracks, and openings along bedding planes, are called "charque." Associated with the charque at many places are gypsum and in smaller quantity celestite.

The native-copper ores have been worked to depths of 200 to 600 meters.

Sulphide ores.—The occurrence of sulphide ores is restricted to the vetas. They are found in the upper levels of the mines and grade over into native-copper ores in depth. The sulphide ores usually do not extend to depths of more than 150 to 200 meters.

The typical sulphide ore is more highly mineralized than the native-copper ore, and the rock is more uniformly impregnated with chalcocite. Covellite and domeykite occur in very small amount. The average tenor of the sulphide ores was 6 to 8 percent of copper, but hand-sorted ores contained 18 to 20 percent. The color of the sulphide ore unaffected by oxidation is a uniform metallic-looking gray.

Thin sections of the sulphide ore show that ore deposition has occurred, as in the native-copper ore, mainly by replacement of the matrix, but that the process has proceeded much further, even to the point where the matrix was almost completely replaced. Where the ores are of more than average richness, the grains of the rock are also attacked and replaced by chalcocite to some extent. In the leaner sulphide ores the chalcocite occurs as disseminated grains that range from 0.5 to 1 millimeter in diameter.

Oxidized ores.—In the zone of oxidation, the depth of which is generally much less than 100 meters, copper occurs as brochantite, malachite, azurite, and cuprite. Hand-sorted oxidized ores averaged 18 to 20 percent of copper.

Silver ores.—Silver is a very subordinate constituent of the copper ores. Workable silver ore was encountered in only one veta, the Buen Pastor, and its occurrence is described only in the older literature. In this veta native silver alternated with copper. Silver was encountered at a depth of 20 meters, and down to 60 meters there was eight times as much silver as copper. At greater depth the amount of silver decreased. Rich ores are said to have contained 2,400 ounces of silver to the ton and medium-grade ores to have yielded 700 to 1,200 ounces.

The native copper concentrates, with a tenor of 85 percent of copper, contain only 6 ounces of silver to the ton; and the sulphide concentrates, with a tenor of 45 percent of copper, contain only 3 ounces of silver to the ton.

Gangue minerals

The bulk of the Corocoro ores consist of rock in which the matrix has been more or less replaced by native copper or chalcocite. Gangue minerals are abundant only locally, and chiefly in association with charque.

Gypsum is the most abundant and widespread gangue mineral. It is an original constituent of the rocks and occurs also in larger masses filling fractures and surrounding charque. Celestite also occurs in considerable quantity, and barite in smaller quantity.

Treatment of ore

There were at one time five mills for the concentration of native copper ores—the Libertad mill, at the Libertad mine; the San Francisco mill of the Compañía Corocoro de Bolivia; and the Huaichuni, Guallatiri Chico, and Guallatiri Grande mills of the Corocoro United Copper Mines, Ltd., whose three mills used the same water successively. All these mills had similar flow sheets. The ore was crushed, ground, and jigged. The tailings of the jigs were reground and treated on tables. The recoveries ranged from 70 to 90 percent, and the tailings ran from 0.3 to 0.5 percent of copper.

In 1918 and 1919 the two major companies erected flotation plants—the Compañía Corocoro de Bolivia at its San Francisco mill; the Corocoro United Copper Mines, Ltd., a separate mill across the Guallatiri River from the Guallatiri Grande mill, in which the sulphide ores were concentrated. The flotation concentrates ran from 45 to 55 percent of copper.

In 1919 a sulphuric acid leaching plant was erected to treat the lower-grade oxidized ores that were rejected in hand-sorting high-grade oxidized shipping ores.

Genesis of the deposits

Though a syngenetic origin has been advocated, the consensus of opinion regarding the origin of the Corocoro copper deposits has been that they are epigenetic.

Ahlfeld (4) has recently suggested that the ore beds were impregnated by descending cupriferous solutions that had collected in arid basins, and that this original mineralization was later further concentrated by descending cold waters. Most geologists who have studied the deposits regard them as of hydrothermal origin and consider that the mineralizing solutions were genetically related to the belt of dioritic rocks that parallels the belt of native-copper deposits of which those in the Corocoro district are by far the richest.

More diversified have been the views regarding the chemical character of the hydrothermal solutions and the reasons for the deposition of the copper chiefly in the native form. One explanation offered has been that the copper was contained in the mineralizing solutions as carbonate or chloride and was precipitated in the native form in a reducing environment. Geier (2) assumes that the mineralizing solutions were acid thermal waters carrying the metal as chloride or bicarbonate. The metallic copper was precipitated through the absorptive action of the kaolinic material in the ore-bearing beds liberating acids that dissolved the ferric oxide and bleached the rock. But a greater number of students of these deposits (1, 3) have postulated normal hydrothermal solutions containing the copper as a sulphosalt and assumed that its deposition in the oxidizing environment of the ferric oxide of the sediments caused its precipitation in the native form. A delicate balance between deposition of native copper and copper sulphide is indicated by the deposition of both in large quantity.

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In 1919 a sulphuric acid leaching plant was erected to treat the low-grade oxidized ores that were rejected in hand-sorting high-grade oxidized shipping ores.

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The Braden copper deposit, Rancagua, Chile

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Introduction

Among the copper deposits of South America two types stand out prominently. One is characterized by the association of quartz, enargite, and pyrite. To this type belong the occurrences at Cerro de Pasco, Chuquicamata, Famatina, and many others. The other type carries quartz, tourmaline, pyrite, and chalcopyrite. Examples of this type are more common in Chile than elsewhere, and among them we mention Tamaya, Las Condes, Peralillo, and Braden.

The Braden mine seems to be the unique example of a copper deposit lying in and about a large explosive volcanic vent. It furnishes one of the most striking evidences on record of the intimate connection in origin between mineralizing solutions and bodies of igneous rock, for in the Braden crater rising mineralizing solutions and igneous masses followed the same paths and alternated with each other. The geologic history is not only unusual but also complex, comprising three periods of igneous intrusion, three periods of mineralization by ascending solutions, uplift and tilting of the land, erosion of the surface, enrichment of the ores by descending waters, and other events.

The Braden mine, or El Mineral Teniente, as the Chileans call it, is in the western Cordillera of Chile 30 miles northeast of Rancagua, a town a couple of hours' ride by train south of Santiago. It lies on the south slope of the upper valley of the Teniente River, a small tributary of the Coya, which empties into the Cachapoal River. The railroad from Rancagua leads steadily upward, following the torrential streams till the mine is reached. The slopes are covered by brush and small trees to within a few miles of the mine; beyond this there is little or no vegetation, and the whole region becomes alpine in aspect. At the mine the altitudes range from 7,458 to 9,642 feet, and a few miles east of the mine the divide is reached at 11,800 feet. Beyond this lies the longitudinal valley of the Maipu, beyond which, 28 miles from the mine, rises the main snow-covered divide of the western Cordillera, with altitudes as great as 18,000 feet.

Geologic history

Cerro Negro series

The first event recorded in the rocks of the vicinity of the Braden mine was the eruption of a great series of volcanic rocks now forming the rudely bedded series of Cerro Negro, the Caletones Cliffs, and the valley of the Puquios. We have termed these the "Cerro Negro series." The volcanic mountains, probably several in number, from which these rocks were erupted have been so dissected by stream erosion that detailed geologic studies covering large areas would be needed to discover even their whereabouts. The rocks of this series are all products of volcanic eruption, lava flows alternating with tuffs. In age they are probably Tertiary, and they constitute the oldest known formation of the district, antedating the formation of the Braden crater and of the ore deposits. Mineralization of the series was confined mainly to scattered veins of negligible commercial importance.

Intrusions of andesite porphyry

Into this volcanic series there was later forced from below a great intrusive mass, which displaced and pried apart the beds of the older rock and solidified to form andesite porphyry where it cooled rapidly and quartz diorite where its cooling was more leisurely. Complete gradations are traceable from the andesite porphyries into quartz diorites. Because the andesite porphyries are more abundant than the quartz diorites in the mine workings, and because the name "andesite" has long been applied to these rocks in the company reports, it is best to use "intrusive andesite porphyry" as a comprehensive name for the formation.

The series constitutes a belt from about 1.5 to 5.5 kilometers wide, as is shown in figure 50. The further extent of these rocks northeast and southwest is not known. They are bounded on the northwest and southeast by the surface volcanic rocks of the Cerro Negro series.

At its borders the andesite-diorite mass sends off wedgelike branches or sills which split apart the beds of the bordering Cerro Negro series. These branches can be clearly traced into continuity with the main body of andesite-diorite and are similar to it in composition. These relations show that the andesite porphyries and quartz diorites are intrusives forced from below in a molten condition into the older rocks of the Cerro Negro series. Their intrusive origin is further demonstrated by their coarseness of grain in many localities.

Though varying in coarseness and local brecciation, the rocks of this series do not show flow lines, spherulites, amygdaloidal structure, or other features characteristic of surface volcanic rocks, and no tuffs are interbedded with them. In these respects they contrast greatly with the bordering Cerro Negro series.

First or pre-explosion period of mineralization

During the earth movements that were gradually uplifting the Cordillera region the intrusive andesite porphyry mass became fractured, bleached, and tourmalinized over considerable areas and in places slightly mineralized with pyrite.

The andesite porphyries and quartz diorites have in many places been so profoundly altered that their original character can be proved only by gradations from the altered into the fresh types. This alteration was accompanied by sparse deposition of sulphides and constituted the first mineralization. The earliest phase of the alteration consisted in the development of magnetite in dark cloud-like masses and of disseminated biotite. The rock next became strongly chloritized, with more or less sericite, both minerals attacking the dark silicates and the feldspars. The groundmass was more or less silicified and in places was converted into a mosaic of small quartz grains. Rutile is abundant in many sections. Lastly black tourmaline developed, replacing all the other secondary minerals as well as the feldspars.

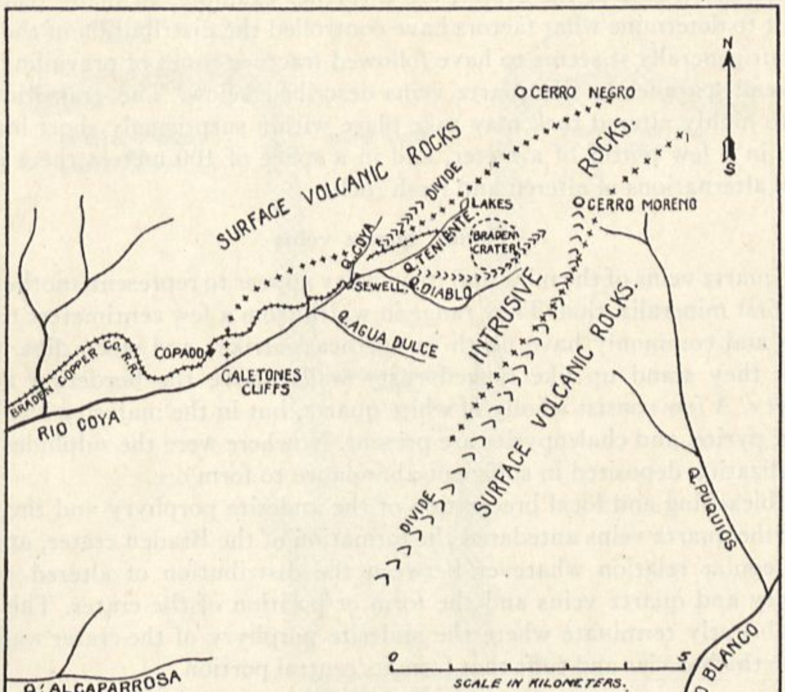


FIGURE 50.—Map showing the general location of the Braden crater, Chile, and the approximate limits of the intrusive mass of andesite porphyry and quartz diorite.

Strong development of sericite led to bleaching of the rock, and in the most altered parts the chlorite has disappeared and the entire rock is a confused aggregate of quartz and sericite. The development of black tourmaline was a usual but not invariable accompaniment of the bleaching. Rather commonly the tourmaline coats fractures or has replaced the rock along incipient fractures, forming veinlets with irregular borders. In brecciated parts of the andesite porphyry the matrix of the breccia was the first part to be tourmalinized. Typical breccias of this origin show white to cream-colored fragments of altered andesite porphyry in a dark-gray to black matrix. In more highly tourmalinized breccias the fragments are partly tourmalinized; in some of these the original feldspar phenocrysts remain only as white spots still untouched. Finally, the entire rock, fragments and matrix, may have become a black mass almost wholly tourmaline.

The bleached and tourmalinized areas, although irregular in size, form, and distribution, are found throughout the observed length of the intrusive mass. The conspicuous light color of large areas on the ridges southeast of Sewell is due to this alteration. A few miles north of the mine a small but conspicuous black knob consists of the brecciated andesite porphyry largely replaced by black tourmaline. In the immediate vicinity of the Braden mine the altered areas are mainly on the east and northeast sides of the crater. The so-called "Gypsum Cliffs," about 1 kilometer northeast of the crater, are a further example. In many places it is difficult to determine what factors have controlled the distribution of the alteration, but generally it seems to have followed fracture zones of prevailing northeast trend, paralleling the quartz veins described below. The transition from fresh to highly altered rock may take place within surprisingly short intervals, locally in a few tenths of a meter, and in a space of 100 meters there may be several alternations of altered and fresh rock.

Pyritic quartz veins

The quartz veins of the mine and its vicinity appear to represent another phase of the first mineralization. They range in width from a few centimeters to 5 or 6 meters and commonly have north to northeast strikes and steep dips. On the surface they stand up like ragged rusty walls above the bordering andesite porphyry. A few consist wholly of white quartz, but in the majority black tourmaline, pyrite, and chalcopyrite are present. Nowhere were the sulphides of this mineralization deposited in sufficient abundance to form ore.

The bleaching and local brecciation of the andesite porphyry and the formation of the quartz veins antedated the formation of the Braden crater, and there is no regular relation whatever between the distribution of altered andesite porphyry and quartz veins and the form or position of the crater. The quartz veins abruptly terminate where the andesite porphyry of the crater walls gives place to the breccias and tuffs that form its central portion.

Formation of the Braden explosive vent

The event of supreme importance in the geologic history of the mine area was the great explosion that produced a volcanic vent and shattered the bordering andesite porphyry in such a manner as to provide ample open spaces for the deposition, somewhat later, of ore minerals. This explosion was probably caused by the upward progress of a body of molten and partly molten material beneath the present vent. A sudden upward pulsation of this hot mass, bringing it into contact with portions of the andesite-diorite which lay nearer to the surface and whose fractures were filled with ground water, and the violent conversion of this water into steam were the probable causes of the explosive eruption. The gases imprisoned in the magma itself probably served as a cooperating factor in the explosion.

The vent produced was certainly more than 1,000 meters in depth, probably nearer 2,000 meters, and was about 1,000 meters in average width, tapering somewhat from top to bottom. The material erupted consisted mainly of fragments of the andesite porphyry mass that formed the crater walls mingled with smaller numbers of fragments of alkali porphyries (dacite porphyry, granite porphyry, and latite porphyry) that apparently represent the upper parts of the intrusive mass that produced the explosion and was shattered by it (fig. 51).

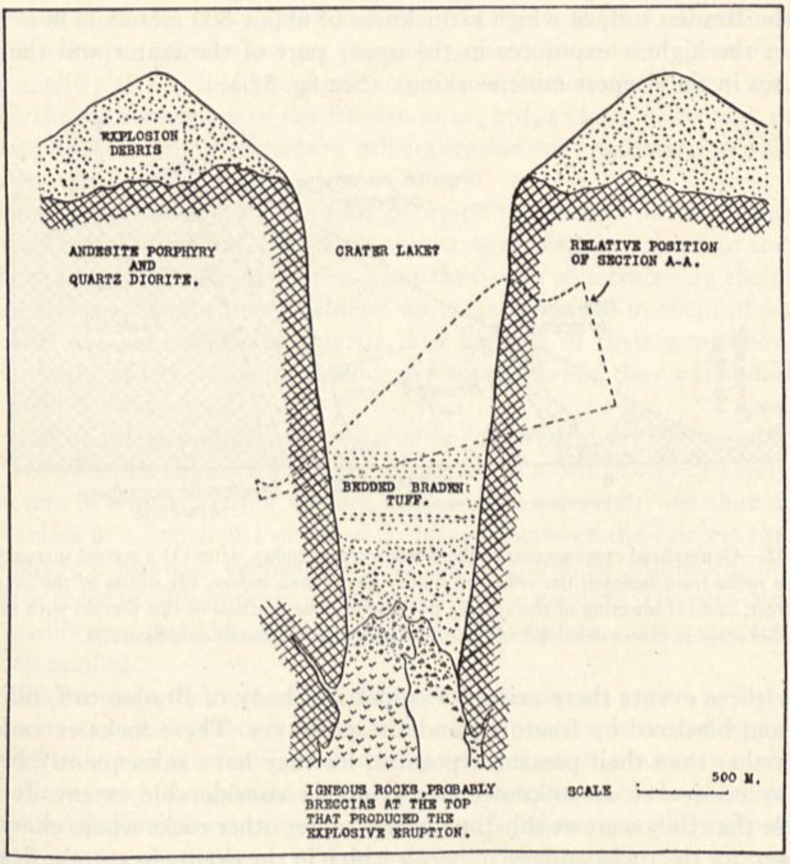


FIGURE 51.—Idealized reconstruction of the Braden crater not long after the explosion, when some of the débris from the explosion had fallen back and had been washed back into the vent. Bedding in some of the Braden tuff suggests that a lake occupied the vent at this period.

The eruption appears to have been solely an explosive shattering of rocks already solidified. No molten or partly molten material was ejected from the vent as lava flows or showers of pumice, and it is probable that steam was the principal gas given off. The débris of the eruption in part fell back into the vent, filling its lower portion, but most of it was probably strewn over the surface bordering the crater.

Next ensued a period of quiescence as regards eruptive activity during which surface processes assumed the leading rôle. There are evidences that at this time the depression produced by the explosion was occupied by a lake (see fig. 51), while at the same time rains and freshets gradually washed back into the hole part of the débris which the eruption had strewn over the surface. During its redeposition within the vent much of this débris acquired a bedded structure, beds of fine material alternating with coarse fragments, and many of the fragments became partly rounded—in fact, the evidence of the existence of a lake consists in this bedding and the rounding of the fragments. This filling constitutes the Braden tuff, of which a thickness of about 800 meters is now in view between the highest exposures in the upper part of the crater and the lowest exposures in the deepest mine workings. (See fig. 52.)

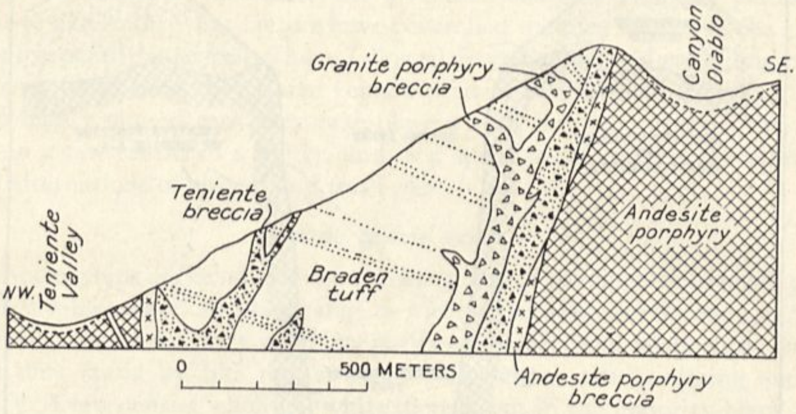


FIGURE 52.—Generalized cross section of the Braden crater today, after (1) a second intrusion of the igneous rocks from beneath the crater to higher levels than before, (2) tilting of the land to the southwest, and (3) lowering of the surface by erosion. The position of this section with respect to the earlier stage in crater development is indicated by the broken lines in figure 51.

After these events there existed a cylindrical body of Braden tuff, filling the crater and bordered by fractured andesite porphyry. These rocks extended upward farther than their present exposures, for they have subsequently been cut down by erosion to an unknown but probably considerable extent. It is also probable that they were at this time buried under other rocks whose character is unknown, for the rocks and ore minerals which in the events next to be described were brought into the position of the present Braden mine lack the features usually found in ore and rocks crystallized at or very close to the surface.[1]

Second or main period of primary mineralization

The explosive eruption that formed the Braden vent greatly shattered the andesite porphyry composing its periphery. The shattering, as might be expected, was exceedingly irregular, fracture planes trending in every conceivable direction, though in a few localities a predominant trend, parallel to the crater wall, is

[1] The literature contains many examples of explosion vents more or less similar to the crater of the Braden mine. Some examples are the occurrences in Scotland, those described from the Suabian highlands in Germany, and also the explosion vent of Cripple Creek, Colorado, in which the steep or even overhanging walls have been exposed by mine workings. At Cripple Creek, however, the mineralization with gold tellurides followed shortly after the cessation of the volcanic activity.

discernible. The width of the zone of most intense shattering is uneven, ranging from 100 to 200 meters to more than 600 meters, the widest portions are on the northeast side of the crater.

After the interval, during which the crater became partly filled with the Braden tuffs, mineralizing solutions, rising principally about the periphery of the old vent, deposited quartz, tourmaline, biotite, pyrite, and chalcopyrite in irregular fractures in the andesite porphyry and formed large bodies of mineralized material with a copper content in most places between 0.50 and 1.50 percent, though locally slightly richer. Thus was initiated the formation of the great ore bodies that are the main resource of the Braden mine, but, as later explained, their enrichment by descending secondary mineralization was necessary to raise their copper content to a workable grade.

Although the Braden tuffs certainly occupied the vent of the old crater at the time of this mineralization, they were almost nowhere mineralized to the extent of more than 0.50 percent of copper. That they were penetrated by the mineralizing solutions is shown by the almost universal presence in them of scattered fine grains of pyrite and chalcopyrite, but because of their somewhat clayey matrix and the nearly complete absence of fracture planes, they were not a favorable site for ore deposition.

The ores of the second period consist of andesite porphyry traversed by veinlets of ore minerals from a millimeter or less up to a centimeter or rarely 2 or 3 centimeters in width. Within the ore bodies there are rarely less than a dozen such veinlets in a length of 1 meter of porphyry. Between the veinlets the andesite porphyry commonly carries scattered small grains of sulphides, but more than 90 percent of the copper is undoubtedly in the veinlets. The ores commonly break readily into small blocks along the sulphide veinlets, a characteristic favoring cheap mining.

The predominant ore minerals of this period are quartz, pyrite, and chalcopyrite; black tourmaline, though almost universally present, is subordinate; biotite was noted only in a few places and in very minor amounts but was clearly contemporaneous with the sulphides. The relative abundance of the three principal minerals varies considerably even in adjacent veinlets; quartz is abundant in some and almost absent from others; pyrite is the dominant sulphide in some, and chalcopyrite in others. Commonly the several ore minerals are irregularly associated, but in some veinlets the quartz is mostly next to the walls and the sulphides in the center.

Of much economic importance is the tendency for pyrite to increase and for chalcopyrite to decrease in relative abundance outward in all directions from the periphery of the crater. In many of the crosscuts into the footwall the passage from ore to material below workable grade is practically coincident with the transition from predominant chalcopyrite (somewhat enriched) to predominant pyrite.

Intrusion of alkali porphyries and breccias

The next event in the complex history was the intrusion of masses of magma which crystallized as dikes and irregular bodies of dacite porphyry, and of bodies of partly or wholly solidified and brecciated dacite and latite porphyries, giving rise to what has been termed the Teniente breccia. These intrusive masses are confined, so far as known, to the crater or its near vicinity. The Teniente breccia forms a nearly continuous sheath between the filling of Braden tuff and the andesite porphyry of the crater walls, sending off, however, irregular ramifications into the central portions of the tuff mass. A single outlying body of Teniente breccia occurs in the andesite porphyry a short distance south of the vent, near the divide between Teniente Valley and Canyon Diablo. The details of surface distribution are shown on the geologic map (fig. 53). This locality, by reason of the explosive eruption and the other events already described, was a weakened area that could be readily penetrated by intrusive bodies, but a further explanation of the localization of these rocks near the vent is probably to be found in their derivation from the same deep source as the magma that produced the crater explosion. Evidence for this belief is found in the identity of the porphyries intruded at this time, in appearance and composition, with porphyry fragments in the Braden tuff that are believed to have been thrown out during the explosive eruption. These intrusions probably constituted a second and higher upsurging of molten and partly molten material from the same source as that which produced the eruption. That a second explosion did not result is possibly due to the fact that this intrusion, unlike the first, did not come into contact with cool wet rocks, being preceded by mineralizing solutions, which heated the rocks through which they passed and sealed with ore minerals fractures previously occupied by ground water.

The ascending magmas were of two types, one having the composition of dacite and the other of latite, both rich in alkalies and probably related in origin. For the most part these magmas solidified completely before they reached their present position but continued their upward progress under the pressure of still molten magma below, becoming intimately brecciated by friction during the later part of their ascent (Teniente breccia). Some portions of the dacite magma appear to have worked their way upward more rapidly through fissures in the andesite porphyry, reaching their present position in a molten condition and there solidifying to form the dikes of massive dacite porphyry. (See fig. 51.) Complete gradations are traceable locally from massive dacite porphyry into Teniente breccia composed wholly or mainly of dacite porphyry fragments. The intrusive origin of the breccia is further indicated by the typically dikelike forms which it locally assumes.

Brecciation of ores of the second period

As explained above, the Teniente breccias were, in the main, masses of rock fragments forced upward by the pressure of molten and partly molten material below. In their upward progress they exerted a considerable friction on the andesite porphyry of the walls of the vent. Although the fractures in that porphyry had been partly sealed by sulphides during the second mineralization, it was still a weak body of rock, and large masses of it were intimately brecciated during the intrusion of the breccia. In this manner were formed the bodies of andesite porphyry breccia which characterize the periphery of the vent and which normally lie between Teniente breccia and massive andesite porphyry, although in some localities Teniente breccia has been forced between the two into direct contact with massive andesite porphyry, as on the east side of the vent. (See fig. 53.)

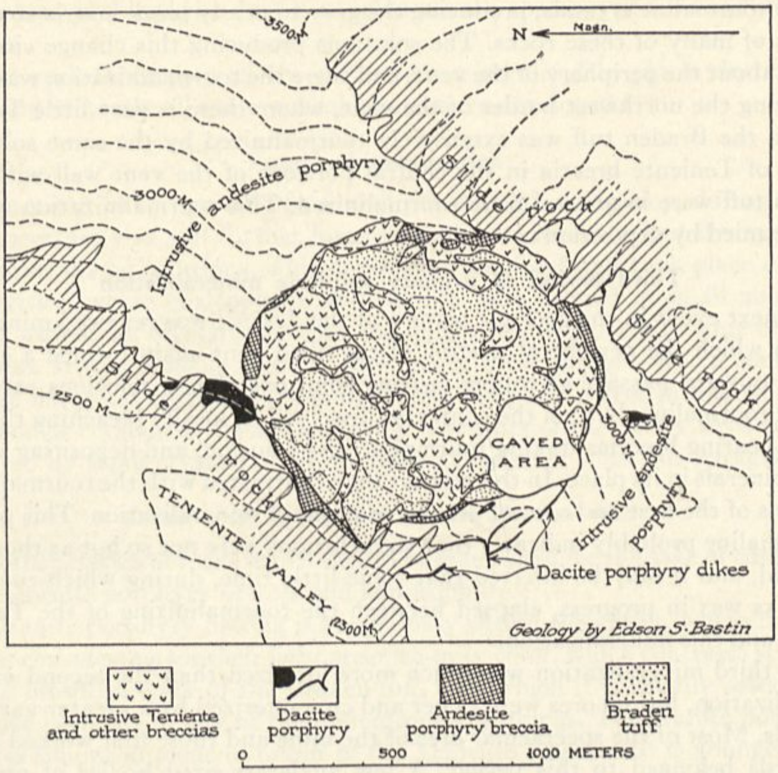


FIGURE 53.—Geologic map of the Braden mine.

As might be inferred from this mode of formation of the andesite porphyry breccia, no sharp boundary line can usually be drawn between it and the Teniente breccia, yet the mapping of the distribution of the two breccias offers no serious difficulties, for the transitions from breccias composed almost wholly of andesite porphyry fragments into breccias carrying only scattered fragments of andesite porphyry commonly takes place in the space of 2 or 3 meters or less. At this stage in the history of the deposit the metal content of both these breccias was in pyrite and chalcopyrite contained in fragments—sulphides that were originally deposited along fractures in the andesite porphyry during the main mineralization. The copper content averaged considerably less than 1.5 percent. The open texture of the breccias was, however, especially favorable to the subsequent enrichment by descending solutions, and by that process large bodies of breccia became converted into ore. In places also their copper content was augmented by sulphides deposited during the third and last period of primary mineralization, as shown below.

Tourmalinization of the alkali breccias

Originally the matrix of most of the Teniente breccia was composed of small fragments similar in composition to the larger fragments, but shortly after their intrusion rising solutions partly replaced the matrix of most of these breccias by minute tourmaline crystals, producing the gray to nearly black matrix so characteristic of many of these rocks. The solutions producing this change circulated chiefly about the periphery of the vent, and there the tourmalinization was greatest. Along the northwest border of the vent, where there is very little Teniente breccia, the Braden tuff was extensively tourmalinized by the same solutions. Bodies of Teniente breccia in the central portions of the vent well within the Braden tuff were in general little tourmalinized. This tourmalinization was not accompanied by deposition of sulphides.

Third period of primary sulphide mineralization

The next event in the geologic history of the deposit was renewed mineralization, in which the peripheral portion of the filled vent again formed a channel for the upward passage of copper-bearing solutions. These solutions rarely deposited tourmaline, but, on the contrary, dissolved it, locally bleaching the tourmaline-bearing breccias, taking tourmaline into solution, and depositing various other minerals in its place. In this respect they contrasted with the tourmalinizing solutions of the first and second periods of primary mineralization. This poverty in tourmaline probably indicates that the solutions were not so hot as those that preceded, and it may be inferred that some little time, during which cooling of the rocks was in progress, elapsed between the tourmalinizing of the Teniente breccia and this mineralization.

This third mineralization was much more localized than the second or main mineralization, but its ores were richer and characterized by a greater variety of minerals. Most of the spectacular ores of the mine and those first worked by the Spaniards belonged to this period. A few moderate-sized bodies of ore were formed, the "bornite" ore body being an example, but many of the ore bodies are too small to be of much value. In places the copper content of the earlier-formed main ore bodies was increased by additions of sulphides at this period.

The sealing of the fractures in the andesite porphyry by sulphides of the second period and the sealing of the pores of the various breccias by tourmaline resulted in confining the active circulation of the later solutions mainly to scattered zones of fracturing formed since the second mineralization. Open spaces being comparatively rare, replacement became an important mechanism of mineralization.

The third period of mineralization was characterized by a great variety of minerals, not all of which are present in any one locality. In the following list those that occur only rarely or in small amounts are starred:

Sulphides:	Arsenosulphides:	Oxides:
Pyrite.	Tennantite.	Quartz.
Chalcopyrite.	* Enargite.	Sulphates:
Bornite.	Carbonates:	Anhydrite.
* Galena.	Siderite.	* Barite.
* Sphalerite.	Rhodochrosite.	Tungstates:
* Molybdenite.	* Calcite.	* Hübnerite.

Gypsum is secondary after anhydrite. The minerals listed above are present in very different proportions in different parts of the mine; in the bornite ore body, for example, the predominant minerals are bornite, chalcopyrite, and siderite; in certain small ore bodies associated with bleached Teniente breccia in the Teniente workings the dominant minerals are chalcopyrite, tennantite, and anhydrite.

All the rock formations of the mine were mineralized in places during this period, and in nearly all some workable ores were developed.

Fourth mineralization

Evidence can be recognized of a fourth phase of mineralization, during which the temperature was still further lowered. It represented the last dying effects of the mineralizing solutions. This deposition was local and took place only in open cavities, where chalcopyrite and bornite were formed in small amounts, together with small crystals of barite and quartz and wonderfully large crystals of gypsum. It was possible to crawl into one of these cavities, which contained one large flat-lying crystal of gypsum 10 feet long and 3 feet in diameter and many smaller crystals of the same mineral. The sides of the cavity were more or less coated by small crystals of all the minerals referred to in this paragraph.

Other rock formations of the Braden vent

Two other classes of rocks which should be mentioned for the sake of completeness are granite porphyry breccia and lamprophyre.

The granite porphyry breccia is known only within the crater, where it forms outcrops conspicuous for their light greenish-gray color, which contrasts strongly with the brownish color of the Braden tuff, with which it is usually associated. It has not been cut in any of the underground workings. The granite porphyry breccia is similar in mode of origin to the Teniente breccia but is younger than the period of tourmalinization that followed the intrusion of the Teniente breccia, and with the exception of the single dike of lamprophyre it is the youngest formation of the crater. It is probably older than the third period of primary mineralization, as is indicated by the presence in it of small amounts of sulphides.

The lamprophyre occurs as a single dike about 2 meters in average width exposed on the surface on the southwest side of the crater near the divide between Teniente Valley and Canyon Diablo, and exposed underground in the Regimento workings. It appears to be the youngest rock of the district and is unmineralized.

Erosion and chalcocite enrichment

In the further history of the Braden deposit, tilting and uplift of the land, erosion by streams, and the action of the air and surface waters upon the ores assumed the leading rôles. At some period, not definitely known but subsequent to all the events that have been described, the whole region about the Braden mine was tilted and probably also uplifted, so that the volcanic rocks of the Cerro Negro series and the Braden tuffs, deposited in a nearly horizontal position, assumed their present attitude, with dips of 15°–20° SE. (See fig. 52.)

At this time there were present around the periphery of the old vent large bodies of rock mineralized to the extent of about 1 to 1.25 percent of copper and a few small bodies much more highly mineralized. Further mineralization was necessary to form large bodies of workable ore, and this was accomplished by downward enrichment. From the end of the last period of primary mineralization to the present day the country about the crater has been continuously subjected to degradation, and the combined action of the air and of waters of surface origin led to the oxidation of the copper-bearing sulphides and the taking into solution, mainly as copper sulphate, of much of the copper. Some of the copper was redeposited in the near-surface oxidized zone as cuprite, chrysocolla, and other oxidized copper minerals; but much of it was carried downward in solution and redeposited as chalcocite where these solutions came into contact with primary pyrite and chalcopyrite, the latter being always more easily replaced. This process resulted in notable enrichment, bringing the large bodies of 1 to 1.25 percent material formed during the main primary mineralization up to 1.5 to 4 percent or even higher in copper and rendering them commercially workable.

Evidence of chalcocite enrichment is observable immediately below the heavily leached capping of the ore bodies. Downward, its extent is greatest under the ridge on the east side of the crater and least under Teniente Creek.

Mining development has drained most of the mine to a point below the original water level, and the best evidence now available as to the original position of this level is afforded by the lower limit of oxidation, for oxidation cannot readily go on below the permanent ground-water level. With due allowance for such oxidation as has occurred since the mine was opened, the lower limit of oxidation is found to extend locally almost, if not quite, to the lower limit of chalcocite enrichment.

This overlapping of the zones of oxidation and enrichment is believed to be the result of moderate uplift since most of the chalcocite enrichment took place. Just before this uplift the ground-water level probably stood 100 to 200 and in places even 250 meters above its present position. Evidences of geologically recent uplift are not confined to the ores but are found in the topography as well.

Chalcocite is the only secondary copper sulphide present in important amounts in the zone of chalcocite enrichment, although covellite and bornite were noted. The development of chalcocite is greatest in the upper part of the enriched zone and gradually decreases in depth. In the upper part of the zone chalcopyrite has, in a few places, been almost completely replaced by chalcocite, while commonly only a thin outer layer of the pyrite is affected. In the lower part of the zone chalcocite commonly forms thin films along every fracture, however small, in the chalcopyrite, while pyrite is unaffected.

Secondary minerals that appear to have been deposited contemporaneously with chalcocite are covellite, bornite, kaolin, and rarely colloidal silica. Secondary bornite is very rare and was noted only in the Teniente breccia, where it replaced small chalcopyrite fragments; nearly all of the bornite of the mine is a primary mineral of the third period. Kaolin is locally abundant in the upper and middle parts of the chalcocite zone, where it has filled what were small open spaces in the ores. Commonly it has absorbed copper sulphate from the enriching solutions and is pale greenish rather than white.

The main ore bodies appear to be practically limited below by the lower limit of chalcocite enrichment. All workable ore bodies that have been found below the zone of enrichment are small and are primary ores of the third period.

Oxidation

The oxidized portions of the ore bodies are characteristically rusty in appearance and softer and less coherent than the sulphide ores. The characteristic minerals are the following, those found only in a few places or in small amounts being starred:

Oxides:
- Limonite and possibly other hydrous oxides of iron.
- Cuprite.
- * Tenorite.

Carbonates:
- Azurite.
- Malachite.

Silicates:
- Kaolin.

Sulphates:
- Chalcanthite.
- Melanterite.
- * Spangolite, basic aluminous sulphate of copper.
- Gypsum.
- * Epsomite.

Amorphous minerals variable in composition:
- Chrysocolla.
- Copper pitch ore.
- A translucent to transparent sky-blue mineral having the composition of a basic aluminous sulphate of copper.

Cuprite has commonly replaced chalcocite; it rarely occurs in masses more than a few centimeters across. Azurite and malachite are not abundant minerals and are found mainly as alteration products of carbonate-bearing primary ores of the third period. Chrysocolla, the principal green copper mineral of the mine, occurs mainly as thin coatings on the rocks and ore minerals but is occasionally found in masses several centimeters across, usually filling irregular cavities in association with copper pitch ore.

The ore bodies of the Braden mine are commonly heavily oxidized and leached of a large share of their copper to depths of 50 to 100 meters. An important characteristic of the oxidation is its local extension downward in toothlike form to much greater depths than those indicated above. The largest of these areas of deep oxidation lies beneath one of the principal minor valleys eroded in the volcanic vent.

In most of the workings that expose heavily oxidized materials there are very abrupt transitions from highly leached material with a copper content of less than 1.5 percent or even less than 0.5 percent to ores rich in sulphides and assaying over 2.5 percent and in places over 3.5 percent of copper. These transitions are in some places concomitant with the passage from breccias to massive rock, or from one kind of breccia to another, and in such places they are clearly influenced by marked differences in the perviousness of the various formations to the air and oxidizing waters. In other places transitions equally abrupt occur wholly within massive andesite porphyry and are not accompanied by conspicuous differences in porosity. In the latter places, especially, the abrupt transitions without the intervention of zones rich in oxidized copper minerals and the deep extension of "teeth" of oxidized material to the very bottom of the zone of chalcocite enrichment are indicative of the descent of oxidation at a more rapid rate than chalcocite enrichment. The phenomena of oxidation, therefore, the topographic features, and the relation of the lower limit of chalcocite enrichment to the ground-water level all agree in indicating that the region in which the mine is located has undergone comparatively recent uplift. The uplift acted as a stimulus to erosion; it stimulated oxidation by increasing the distance between the surface and the ground-water level and thus exposing new thicknesses of material to contact with the air; it also stimulated chalcocite enrichment, but as this is a slow process the downward movement of the chalcocite zone since the uplift has been slight. The oxidized zone has in consequence come to overlap the zone of chalcocite enrichment instead of lying uniformly above it, and "teeth" of highly leached and oxidized material have come to penetrate nearly to the bottom of the chalcocite zone between walls of rich and little oxidized chalcocite ore.

Mining operations

This is not the place to describe the methods of mining and smelting adopted at the Braden mine, but a few statements will serve to impress the reader with the magnitude of the operations.

In 1931 the ore reserves consisted of 226,000,000 net tons of ore of an average grade of 2.18 percent of copper.

The ore is mined by a highly developed caving system and descends by an ore-pass gathering system to the main haulage tunnel. Thence it is trammed to the ore bins at Sewell, where the concentrating mills are located. The concentrates are transported 12 kilometers to the company's smelter at Caletones.

Concentration is effected by jigs and tables followed by the flotation process. The mill recovery is about 80 percent. The concentrates are smelted to blister copper at the same place.

The electric power is furnished by the extensive Cachapoal power system, installed by the company.

The copper production from 1928 to 1932 was as follows:

	Short tons		Short tons
1928	109,136	1931	103,770
1929	88,163	1932	49,870
1930	80,993		

Ore deposits at Chuquicamata, Chile

By A. V. Taylor, Jr.
Chuquicamata, Chile

Introduction

Foreword and acknowledgments.—A short foreword to this paper is considered necessary in view of its limitations. Geologic work at Chuquicamata is in a relatively early stage, and most of the efforts of the geologic staff have necessarily been concentrated on problems relating to mine operations. Many interesting problems have presented themselves, but several of them have been barely touched, and none have been thoroughly investigated. Thus, even if the scope of this paper would permit extended discussion, the facts at hand would not warrant it. However, in the course of the work many features have been studied and tentative conclusions reached which are embodied in this paper. They should be read with the understanding that they represent my opinions at this time but are in no sense final or proved. All statements as to conditions prevailing in depth below the shovel pit are necessarily of deductive nature, as the available information is limited to cuttings from churn-drill holes, together with the few mine workings on veins marginal to the main deposit, none of which extend below 650 feet (200 meters) from the surface.

Practically all the ideas here submitted are the result of joint studies by me and Mr. W. S. March, Jr., and Mr. March's assistance in the preparation of this paper is deeply appreciated. Microscopic studies and suggestions by Mr. Mark C. Bandy, of the Chuquicamata geologic staff, have been used with much appreciation. Finally, private reports by Messrs. C. P. Berkey, Paul F. Kerr, and Waldemar Lindgren have been available and are referred to in the text. Further references are given at the end of the paper.

Location.—The copper deposit of Chuquicamata is in northern Chile, in the Province of Antofagasta, in latitude 22°17′ south and longitude 68°55′ west of the Greenwich meridian. It is about 150 miles (240 kilometers) northeast of Antofagasta and about 90 miles (145 kilometers) inland from the coast in a direct line. (See fig. 54.) The Antofagasta & Bolivia Railroad and motor roads to Antofagasta and Tocopilla provide communication with these ports. Calama, a town of 6,000 inhabitants in a small oasis along the Loa River, 20 kilometers south of Chuquicamata, is the only town in close proximity.

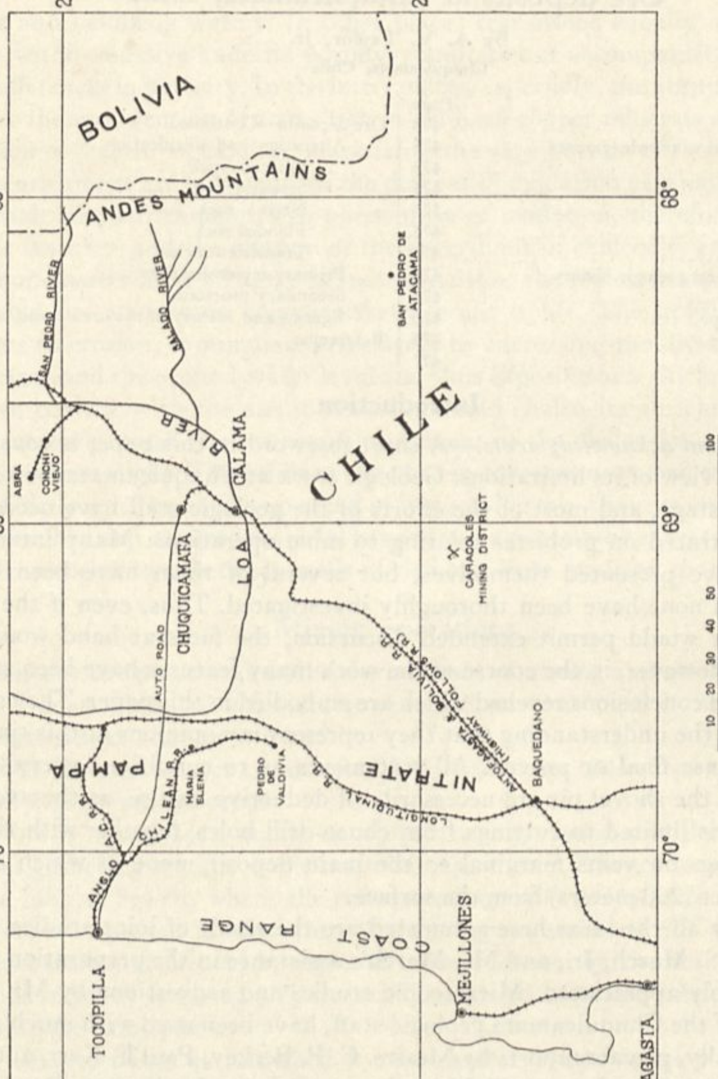


FIGURE 54. Index map showing location of Chuquicamata mine, northern Chile.

History.—The Chuquicamata district has been known for many years. Copper ornaments found in the old Indian graves nearby indicate that the Indians worked the deposit before the arrival of the Spaniards. Later the Spaniards probably worked the mines in a small way (1).

The first real mining operations were carried on by English and Chilean companies from about 1879 to 1912. Their operations were confined to the narrow but rich veins lying mainly on the east side of the present open-cut mine. In 1912 the Chile Exploration Co. was formed to develop and mine the disseminated ore, which was believed to occur in large amounts but was too low in grade to be worked under the earlier small-scale methods. Drilling was successful in blocking out a large quantity of ore, and in 1915 the mine commenced steam-shovel operations. In 1923 control of the Chile Copper Co. and its operating subsidiary, the Chile Exploration Co., passed to the Anaconda Copper Mining Co.

Production.—During 1928 to 1932 the ore mined amounted to 34,407,236 short tons, which produced 996,550,424 pounds of copper. The average grade of the ore was 1.64 percent of copper. All the production to date has come from the oxide zone.

In 1927, an average pre-depression year, the production was 7,709,459 tons of ore with a grade of 1.60 percent of copper. From this ore 219,600,744 pounds of copper was produced.

Geography.—Chuquicamata lies in the northeastern part of the Atacama Desert, one of the world's most arid regions. Rainfalls of a few hours' duration occur but once or twice a year. With the exception of a few desert plants, there is no vegetation. Immediately below the surface there is a crust several feet thick of sand and rocks cemented into a rocklike formation by various salts that could exist only in an extremely arid climate. This extreme aridity has been an important factor in the geologic history of the present ore body, permitting the development in large quantities of sulphate and other water-soluble minerals that would have been carried away in a region of normal precipitation.

The climate is equable, owing to the latitude near the tropic combined with the high altitude, 20° and 90° F. being the extremes of temperature. High winds are prevalent in the winter.

Topography.—Chuquicamata is in the foothills of the high plateau of the Andes Mountains, at an altitude at the mine of 9,317 feet (2,840 meters). The immediate region is one of mature topography characterized by ridges with moderate contours, whose bases are buried in broad alluvial slopes grading gently down into broad valleys and desert basins which, after one of the infrequent rains, may become shallow salt lakes or salares. The mine is on the west side of a low ridge, near the head of a broad alluvial slope that forms a reentrant angle with the mine ridge and a considerably higher ridge to the west.

Geomorphology and geologic history

The characteristic forms of the region in the vicinity of Chuquicamata are those of mature topography which has undergone several stages of uplift. Apparently the present history began with uplift and volcanism in the middle of the Upper Cretaceous epoch. At that time the region was uplifted, and the sediments that had been deposited during Mesozoic time were subjected to gentle folding, accompanied by moderate volcanic activity. This was followed by the deposition, in a retreating sea, of sediments derived from the andesitic volcanic rocks of the preceding period.

The end of the Cretaceous or the beginning of the Tertiary was marked by another period of much stronger uplift, volcanism, and mountain building. Folding of the sediments together with intense faulting was followed by the intrusion of dioritic and granodioritic rocks. It is believed that most of the mineralization in this region is genetically connected with the intrusions that took place at this time. This epoch also saw the beginning of another considerably longer period of andesitic eruption, represented in a thick series of breccias and tuffs, which originally covered the entire region.

The uplift at the end of the Cretaceous period was followed by a long period of erosion and peneplanation, characterized by a damp climate with formation of a deep mantle of soil, wide valleys, and gentle slopes, the land, however, remaining at a relatively high altitude. Near the end of Tertiary time, possibly in the Pliocene, uplift and volcanism again occurred, together with a sudden change to an arid climate. The sediments and volcanic rocks were warped and gently folded, and there was probably some additional uplift of the Andean plateau and the foothill belt. During the Pliocene epoch the long alluvial slopes that are so marked a feature of the present landscape were built; and comparatively deep deposits of stream gravel seem also to date back to that time, indicating that torrential storms were probably more prevalent then than at present.

A final gentle uplift during Pleistocene and Recent time has brought about the entrenchment of these gravel deposits by the present stream channels, further slight warping of the land surface, and probably an interval of increased volcanism, which is now dying out.

Ore deposits

Size and shape

The Chuquicamata ore body, roughly pear-shaped in horizontal section, has been developed over an area 2 miles long by 3,600 feet wide in its greatest dimensions, with a vertical thickness ranging from a few feet at the eastern limit to more than 1,500 feet on the west side. The deepest drill hole (no. 182) bottomed in sulphide ore at a depth of 1,920 feet (585 meters).

Local geology

The host rock for the ores at Chuquicamata is a granodiorite, which is exposed for distances of roughly 8 miles north, 12 miles south, 1 mile east, and 3 miles west of the district, occupying an area of about 80 square miles. Outcrops of similar rock are found in the Conchi Viejo and Abra districts, to the north, and in the Caracoles district, to the south, so that it is probable that the Chuquicamata exposure is only part of a batholith having a length of more than 80 miles and a width varying from 6 to 12 miles. This rock consists of orthoclase and plagioclase feldspars, quartz, hornblende, and biotite. Its alteration phases in the vicinity of the ore body are discussed below.

Structure

Plate 25 is a plan of the fissures and fissure zones that apparently determine the structural control of the ore body. For convenience in discussion, they have been named as shown.

Taken as a whole, these fissures are apparently the result of a strong nearly horizontal force acting at different times in a north-south or northwest-southeast direction. The en échelon arrangement and curving and branching of the fissures indicate the effect of strong torsional forces at the north end of the deposit and straight compressional shear at the south end. As a result of these forces both compressional and tensional fissures have been developed. The compressional fissures are represented by the West fissure, the Zaragoza fissure, the Cabo Fierro fissure (except at the curving north end, where torsion has developed tension), the C-2 fissure, the south end of the Ines fissure, the E-1 fissure, the Panizo fissure zone, the Northeast fissure zone, and the Balmaceda fissure zone. The tensional zones are the Teodora fissure zone, the north end of the Ines fissure zone, and the strongly fractured areas bordering the Cabo Fierro fissure zone and the C-2 and Ines fissures.

The detailed development of these fissures has been worked out as follows:

1. Development of the West fissure and possibly the Zaragoza fissure.

2. Development by continuing pressure of an extensive shear zone along the southern part of the West fissure, forming the Cabo Fierro fissure zone, which leaves the West fissure at about coordinate N. 3200. Northward extension of the same forces resulted in the development of the C-2 and Ines fissures en échelon with the Cabo Fierro zone and strong northwest tensional fracturing of the Teodora zone and the north end of the Ines zone. Tear fracturing took place along the margins of all these zones, causing extensive shattering of the boundary areas.

3. Repetition of the fissuring of no. 2 after and possibly during the first period of quartz mineralization. It is not at all improbable that the movement may have continued unbroken from no. 2, with further movement producing the Panizo fissure zone and the shear-couple development of the Northeast zone between the C-2 fissure and the Panizo fissure zone. Contemporaneously, the E-1 fissure, the Balmaceda fissure zone, and the east-west fissures along the central east side of the mine were formed.

Alteration and silicification

In the vicinity of the Chuquicamata ore body the host rock has undergone extensive alteration and silicification, which appear to be definitely related to the fissure systems. Although it is reasonably certain that the parent rock is all granodiorite, for the purpose of outlining the areas of different intensities of alteration and silicification, the facies of the rock have been divided into six different types—siliceous, sericitic, normal, flooded, transition, and unaltered—as shown by plate 26. The boundaries shown on this map are in general more or less arbitrary, as there is in few places a definite contact, and the types tend to grade into one another. Possibly the sharpest contacts are those of the flooded rock, which generally can be limited within a few feet.

The various rock types have definite relations to the present ore deposit, owing to the effect of their different porosities on the depth of leaching and on the extent of oxidized ore remaining at the present time. These points are further discussed in connection with secondary processes and genesis.

Siliceous rock.—In the vicinity of the Cabo Fierro, Teodora, and Ines fissure zones the original rock texture is completely obliterated and the present rock consists almost entirely of quartz and sericite. At least three ages of quartz are indicated. The quartz that occurs as aggregates and interstitially is cut by quartz veinlets, which in turn are cut by later veinlets. In the hand specimen all three have the same appearance—that of a glassy, colorless mineral. In the Cabo Fierro fissure zone and the central and southern part of the Ines fissure zone the quartz is almost completely shattered and crushed, but there are some indications of a quartz later than the crushed variety.

Sericitic rock.—The rock of sericitic type essentially occupies the areas marginal to the siliceous rock. It consists of a rock containing both original and introduced quartz in which practically all the feldspars have been altered to sericite. It has not undergone the heavy crushing of the siliceous rock but is more of a shattered type, in which the fractures have been filled with quartz, and it lacks the general flooding of the siliceous rock. A characteristic of this rock, though not entirely limited to it, is the occurrence of "lacing veinlets" of quartz. These veinlets are not directional but lace the rock in an intricate pattern, with widths as great as half an inch. It has been suggested[1] that these veinlets represent a late introduction of colloidal silica. However, insufficient work has been done to prove whether this is true or whether they represent filling of fractures by the normal quartz, as elsewhere.

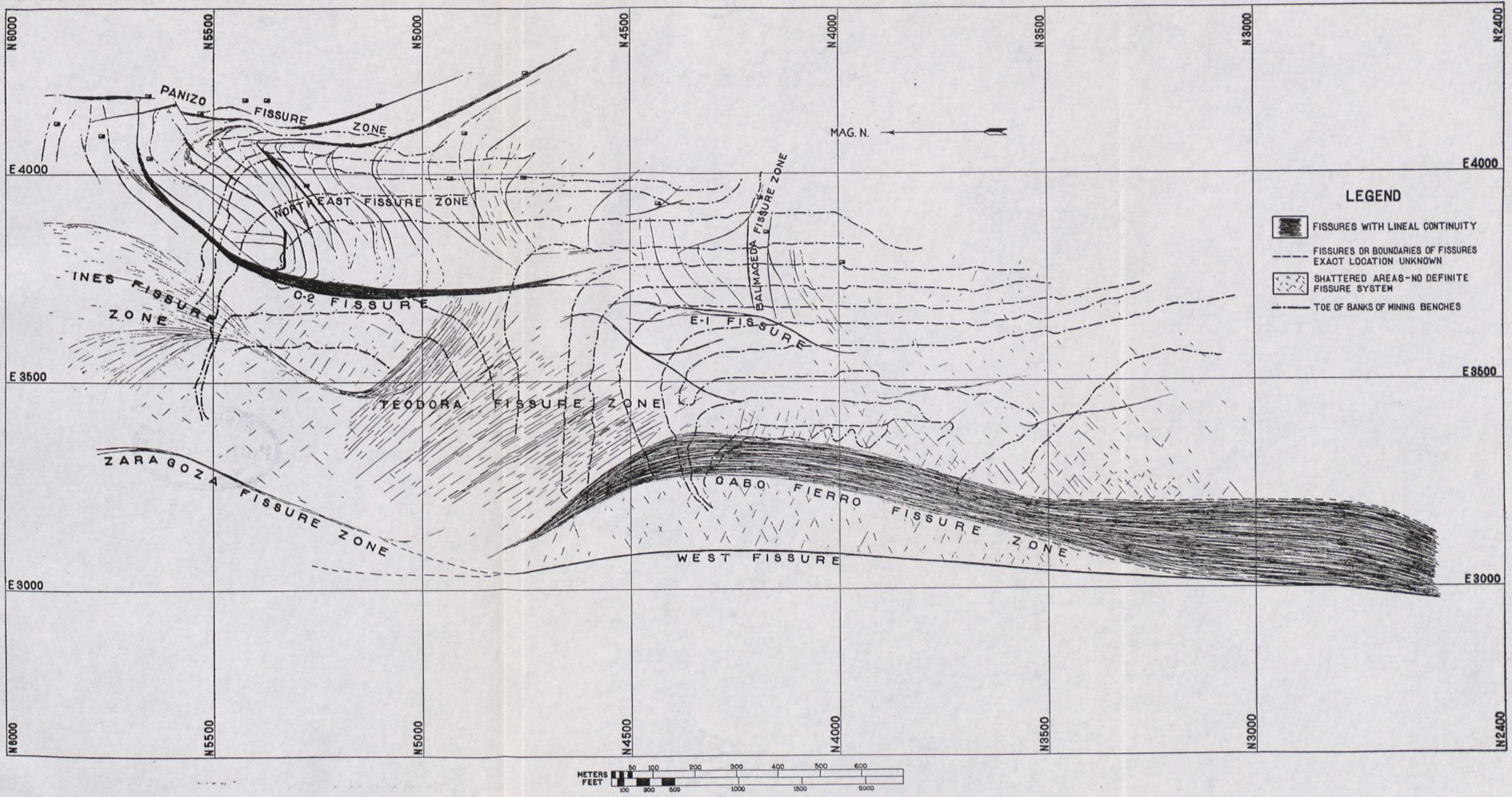
Normal rock.—The chief feature of the normal rock is its porphyritic texture, caused by the presence of large phenocrysts, as much as 2 inches in length, of orthoclase feldspar and quartz "eyes." The original texture of the rock remains, though some of the original feldspars have been converted to sericite. There is very little introduced quartz. With the exception of the orthoclase phenocrysts and the quartz "eyes," this rock is simply a less altered and less silicified type of the sericitic rock. Insufficient work has been done to prove the origin of the orthoclase phenocrysts; it is believed, however, that they represent an end-stage segregation and growth from the original magma. The fact that the large orthoclase phenocrysts are occasionally found in less altered and silicified islands in the sericitic rock indicates that they were formed prior to the flooding of the rock with quartz.

The quartz "eyes" have been described[2] as aggregates of fine interlocking quartz crystals. Further work has indicated[1] that many of them may be actual quartz phenocrysts as much as a quarter of an inch in diameter.

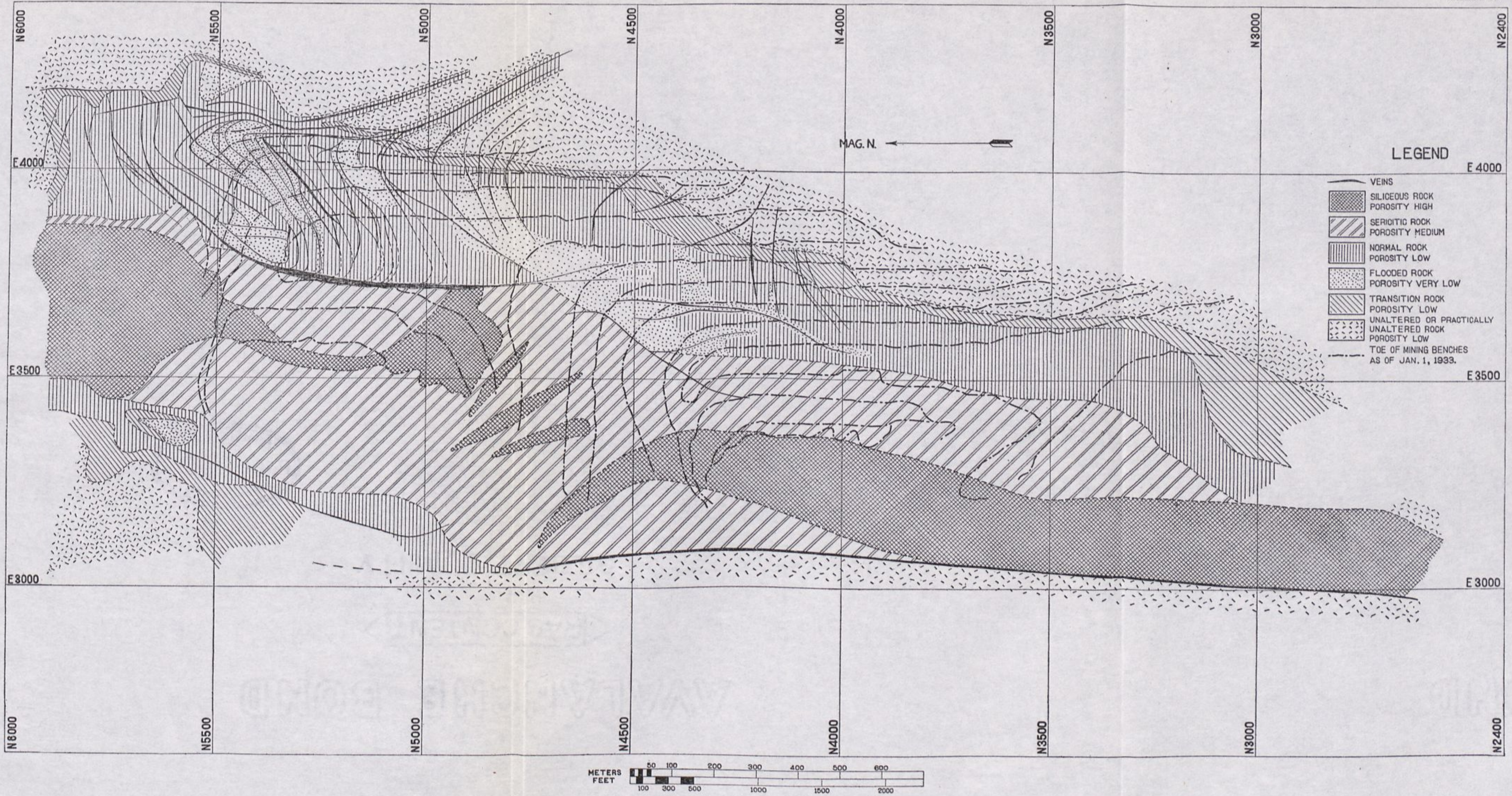
Flooded rock.—The flooded rock is essentially a normal rock that has been flooded with quartz. It differs from the siliceous and sericitic varieties in that the development of sericite is not as prominent, part of the original rock texture remaining, and the quartz has not been fractured or shattered to any great ex-

[1] Bandy, M. C., private report, 1932.

[2] Berkey, C. P., private report, 1930.



PLAN OF FISSURE SYSTEM AT CHUQUICAMATA, CHILE



ROCK ALTERATION AND SILICIFICATION AT CHUQUICAMATA

tent since its introduction. It is therefore a tough rock, which breaks in large blocks, as contrasted to the friable and badly shattered nature of the siliceous rock. One type of this rock has been locally named "porcelain rock," as it resembles porcelain substance. It is very fine grained and is composed chiefly of minute grains of quartz, sericite, and residual feldspar.

Transition rock.—In the transition phase between the normal rock and the unaltered granodiorite there has been a small development of sericite, and the ferromagnesian minerals have generally been altered to chlorite. Quartz is present only as an original constituent of the rock. It represents the marginal zone of alteration. An interesting feature of this transition zone is the occurrence of specular hematite. Practically all the fractures are filled with fine seams and stringers of this mineral or a reddish limonite, which is its oxidation derivative. Also, a few specks are disseminated throughout the rock. The relations have not been studied extensively, but the indications are that the hematite is hypogene and probably came in prior to the copper mineralization. That it is older than the copper mineralization is suggested by the fact that it exists mainly in the transition zone, where there has been little mineralization during the copper epoch; and as it also does not extend far into the unaltered granodiorite, it is believed to represent an introduction at the end of the early quartz period and to have been obliterated in other parts of the mine by the later mineralization. The only alternative possibility is that it represents an unusual low-temperature form marginal to the copper zone.

In this zone the only alteration is a slight development of chlorite from the ferromagnesian minerals. Except for a slight bleaching in places, it is a fresh rock. Locally, sufficient brochantite has been transported from the adjoining rock and deposited in the fractures and joints to bring the copper content up to ore grade. However, this is merely superficial, and no primary mineralization has occurred in this zone.

Primary mineralization

Owing to the extreme depth of enrichment in the district, no drill holes have encountered strictly primary copper ore in the highly mineralized part of the mine; consequently the nature of the primary copper mineralization must be deduced largely from the occurrences in the vein mines on the margins of the district.

The hypogene minerals so far identified in the deposit, other than those composing the granodiorite, with their paragenetic sequence, are listed below:

Quartz: Earliest mineral.

Sericite: Formed from alteration of feldspars, probably during the introduction of early quartz and also at the time of the sulphide mineralization.

Hematite (specular variety): Believed to have been introduced between the periods of quartz and sulphide deposition.

Pyrite: Earliest sulphide mineral.

Enargite and covellite: Apparently replacing pyrite in part.

Tetrahedrite, chalcopyrite, sphalerite, and bornite: Introduced with enargite, but of rare occurrence.

Alunite: Later than period of sericitization; may be supergene.

Apparently, the first stage of mineralization in the district was the introduction of quartz, principally along the Cabo Fierro fissure zone, the Teodora fissure zone, the C-2 fissure, and the Ines fissure resulting in the silicification of this area and the sericitization and lesser silicification of the adjoining zones. After the deposition of the quartz, intense fracturing and shearing again took place in and along the Cabo Fierro, Teodora, and Ines fissure zones and the C-2 fissure. This disturbance either initiated or reopened the veins of the Northeast fissure zone, the E-1 fissure, the Panizo fissure zone, and the Balmaceda fissure zone. That these last-named veins were formed at this time is indicated by the absence of early-stage quartz and of the intense alteration characteristic of the Cabo Fierro and associated fissure zones. After this period of fracturing or possibly contemporaneous with its last stages, came another introduction of quartz, followed or accompanied by pyrite and enargite and probably covellite, succeeded by the development of alunite. The quartz introduced at this time also invaded the rock adjacent to fissures, causing the so-called "flooded rock." The lack of crushing or fracturing of the flooded rock indicates a relatively late introduction of the flood silica. Berkey and Kerr,[3] in a study of ores from a vein mine on the east side of the deposit, state that

> The sulphide minerals are identified as enargite, covellite, pyrite (very abundant), tetrahedrite (small amount), chalcopyrite (rare), and sphalerite (very small amount). The essential ore minerals are enargite and covellite. . . .
>
> Two processes of rock alteration were found to be intimately associated with ore deposition. The first of these is sericitization, which occurred largely at the time of the introduction of the sulphides of copper and was part of the primary mineralization process. The second was alunitization, which was clearly later but appears to have followed closely the period of sericitization. The variety of sericite formed is identified as damourite and represents a primary hydrothermal process. We judge that the associated sulphides were also formed under conditions of primary deposition. The later development of alunite, however, is a more difficult question. It represents the extreme closing stages of this primary process but may possibly be of supergene relation instead. Both processes are normal for these minerals. The evidence seems to indicate the following genetic relation:
>
> First stage: Pyrite with some enargite—crystallization from magma.
>
> Second stage: Enargite chiefly—introduced mineralization from hypogene sources.
>
> Third stage: Covellite—an enrichment modification of the enargite, probably final end-stage effect of hypogene program, but possibly supergene.

Secondary processes

The original or primary deposit has been markedly altered by secondary agents, which have thoroughly oxidized the upper part of the ore body and deeply enriched the sulphide zone. The ore being mined today, together with that to be mined for many years in the future, is largely a result of these processes.

The supergene minerals of the deposit that have been identified are listed as follows:

Oxidized zone—copper minerals

Brochantite, $CuSO_4.3Cu(OH)_2$, basic sulphate of copper. At least 95 percent of the oxide copper is derived from this mineral, which is probably a product of direct oxidation from chalcocite.

Atacamite, $Cu_2ClH_3O_3$, an oxychloride of copper. Occurs mainly near the surface and is rare in the present mine benches.

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[3] Berkey, C. P., and Kerr, P. F., private report, 1931.

Chalcanthite, $CuSO_4.5H_2O$, hydrous sulphate of copper. Fairly common, especially just above the mixed-sulphide ores of the flooded rock in the oxide zone.

Krohnkite, $CuSO_4.Na_2SO_4+2H_2O$, a hydrous sulphate of copper and sodium. Appears to occur in same localities as chalcanthite.

Natrochalcite, $Na_2SO_4.Cu(OH)_2\,(SO_4)_3+2H_2O$. Moderately rare.

Chrysocolla, bisbeeite, and cornuite, copper silicates. Found occasionally, generally in outlying mines.

Turquoise, hydrous copper-aluminum phosphate. Occurs in tiny veinlets and small masses.

Cuprite, Cu_2O. Usually found in fractures in the recently fractured areas and in veins along the east side of the mine; not a common mineral.

Native copper, Cu. Rare.

Oxidized zone—gangue minerals

Blodite, $MgSO_4.Na_2SO_4+4H_2O$, hydrous sulphate of magnesium and sodium.

Coquimbite, $Fe_2(SO_4)_3+9H_2O$.

Melanterite, $FeSO_4+7H_2O$, hydrous ferrous sulphate.

Jarosite, $K_2O.3Fe_2O_3.4SO_3+6H_2O$.

Fibroferrite, $Fe_2O_3.2SO_3+10H_2O$.

Copiapite, $2Fe_2O_3.5SO_3+18H_2O$, basic ferric sulphate.

Mirabilite, $Na_2SO_4+10H_2O$, hydrous sodium sulphate.

Halite, NaCl, sodium chloride, common salt.

Pisanite, $(Fe,Cu)SO_4+7H_2O$.

Romerite, $FeSO_4.Fe_2(SO_4)_3+12H_2O$.

"Limonite," transported and residual iron oxide. Abundant in the leached capping of the siliceous and sericitic areas. There are several varieties which have a relation to the copper enrichment below. These have not been thoroughly studied, but, tentatively, that of maroon color seems to overlie the greatest enrichment, brown next, and orange, red, and brick-red follow. There is also a wine-colored "limonite" derived from oxidation of specularite.

There appear to be other sulphates and oxides which have not yet been identified. They may be mixtures of some of the above.

Sulphide zone

Chalcocite, Cu_2S. The main copper mineral of the zone of enrichment; replaces both pyrite and enargite.

Covellite, CuS. Appears to replace chalcocite and is believed to occur as a supergene as well as a hypogene mineral.

These minerals together with the hypogene minerals quartz, pyrite, sericite, alunite, and enargite, are the principal constituents of the ore body. Plate 27 shows the distribution in vertical range of the oxidized and sulphide ores.

In the shattered, highly porous quartz of the siliceous rock the copper has been completely leached and carried below and deposited as secondary chalcocite. In the shattered areas of the sericitic zone, east of the siliceous zone, there has been considerable leaching, which diminishes rapidly to the east, with copper in the form of brochantite and other oxides and sulphates coming in between the leached capping and the sulphides. These vertical relations are shown by plates 28 and 29, upon which are drawn four typical vertical cross sections of the ore body. The leached capping is generally nonexistent east of the sericitic zone, where the brochantite ore reaches the surface. Exceptions are found in areas such as those of the northeast veins, where the rock is sufficiently fractured along the veins to permit a relatively thick leached zone. Between veins of the Panizo fissure zone the relatively small amount of copper in the rock has been leached to form a thin blanket of secondary sulphide below.

Over a large part of the mine, particularly in the southern part, there is a leached zone between the brochantite ore above and mixed or sulphide ore below. In the southeastern part of the ore body this leached zone has a maximum thickness of 50 meters or more. It is believed that here the leached zone represents the oxidation of the old primary zone lying beneath the earlier zone of enrichment. The minerals in the leached zone are mainly oxides and sulphates of iron, with little or no copper. The indications are that the original rock contained considerable disseminated pyrite but little copper. Drill holes that penetrate the sulphide zone below this leached zone usually disclose only a thin blanket of slightly enriched sulphide ore, thus indicating that only a small amount of copper has been carried below the zone of oxidation.

Toward the west this leached zone becomes thinner, until in many places near the siliceous zone at the south and in the sericitic zone farther north it disappears entirely. There are, however, nearly everywhere indications of a certain amount of leaching, as shown by dropping of assays in the last few meters above the top of the sulphides. This thinner leached band is believed[4] to have been caused by fluctuations of the water table. At Potrerillos the water table has been known to rise as much as 100 feet (30 meters) during a period of storms. The explanation is that with a rise in the water table the water-soluble copper minerals are taken into solution, and with the subsequent dropping of the water table they are deposited as sulphides below. Repetition of this process produced a leached zone just above the top of the sulphides.

Immediately below the top of the sulphides there may or may not occur a zone of mixed sulphides and oxides, locally termed "mixed ores." As there is generally more than 0.05 percent of oxide copper shown in even the deepest holes, the boundary between the mixed and sulphide ores is an assay boundary of 0.20 percent of soluble copper. There is a certain amount of oxidation of the sulphides near the top which gradually and irregularly lessens with depth, although traces are discernible at depths of more than 500 meters below the surface.

The sulphide minerals in the upper part of the sulphide zone are mainly chalcocite and covellite. The chalcocite has replaced pyrite and probably enargite, and the covellite has replaced chalcocite. Enargite is found at increasing depths, indicating its complete replacement by chalcocite in the higher portions of the sulphide zone. In the mixed ores exposed on the pit benches the only sulphide minerals are pyrite, chalcocite, and covellite. Churn-drill cuttings from hole 182 at a depth of 570.0–571.5 meters (1,870–1,875 feet) were examined by M. C. Bandy,[5] who says:

> Quartz, pyrite, and enargite (variety luzonite) were introduced in the order named. The pyrite and especially the enargite were interstitial in the quartz.
>
> The enargite replaces pyrite. Pyrite is practically always associated with either enargite or one of the enrichment minerals.
>
> Chalcocite occurs as veinlets through the enargite and in rims around enargite particles. When etched with dilute acid the chalcocite shows the "cracked porcelain" texture characteristic of supergene chalcocite. In some places the enargite shows bladed texture. This bladed texture is developed by preferential replacement by chalcocite.

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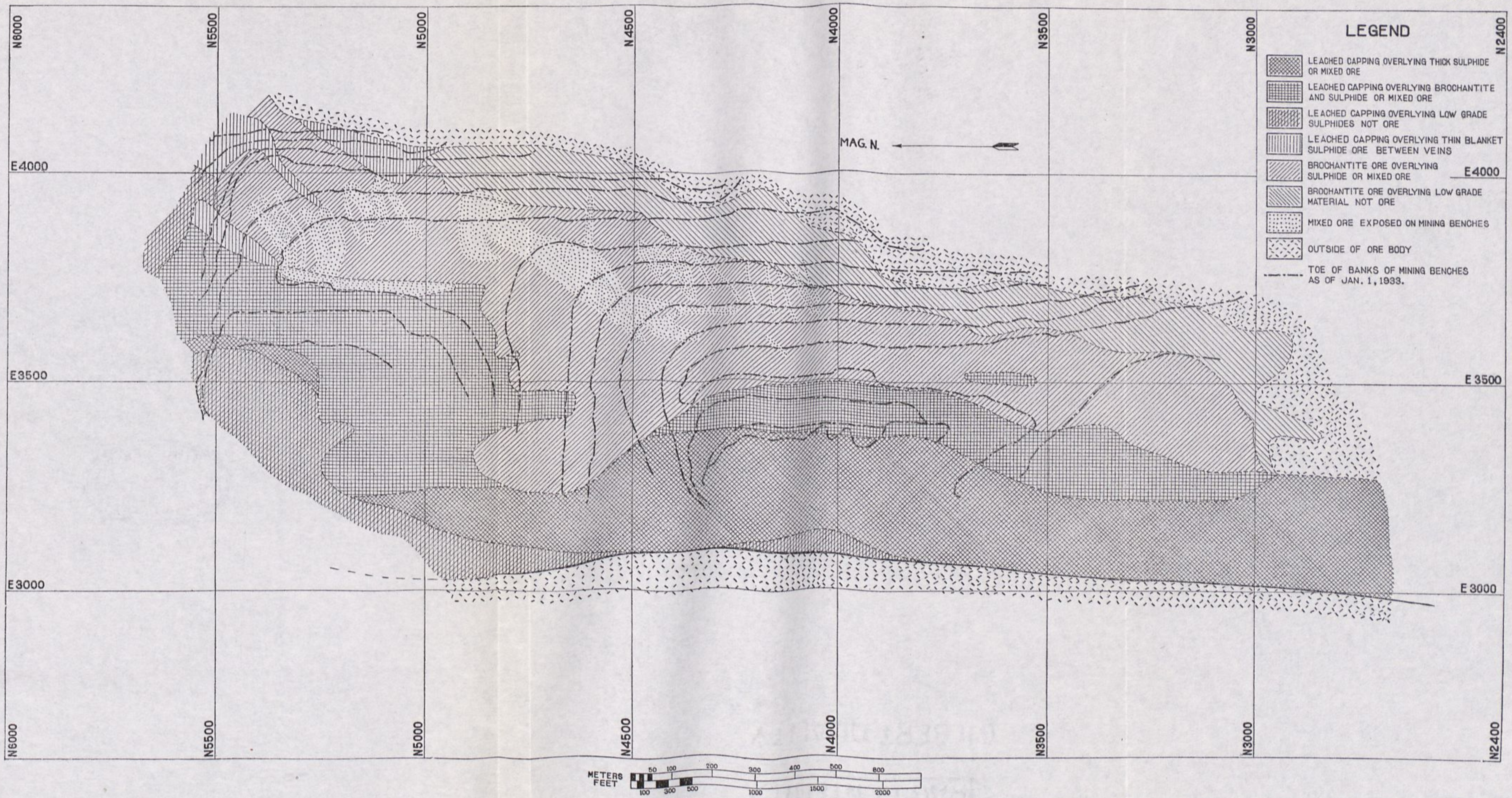
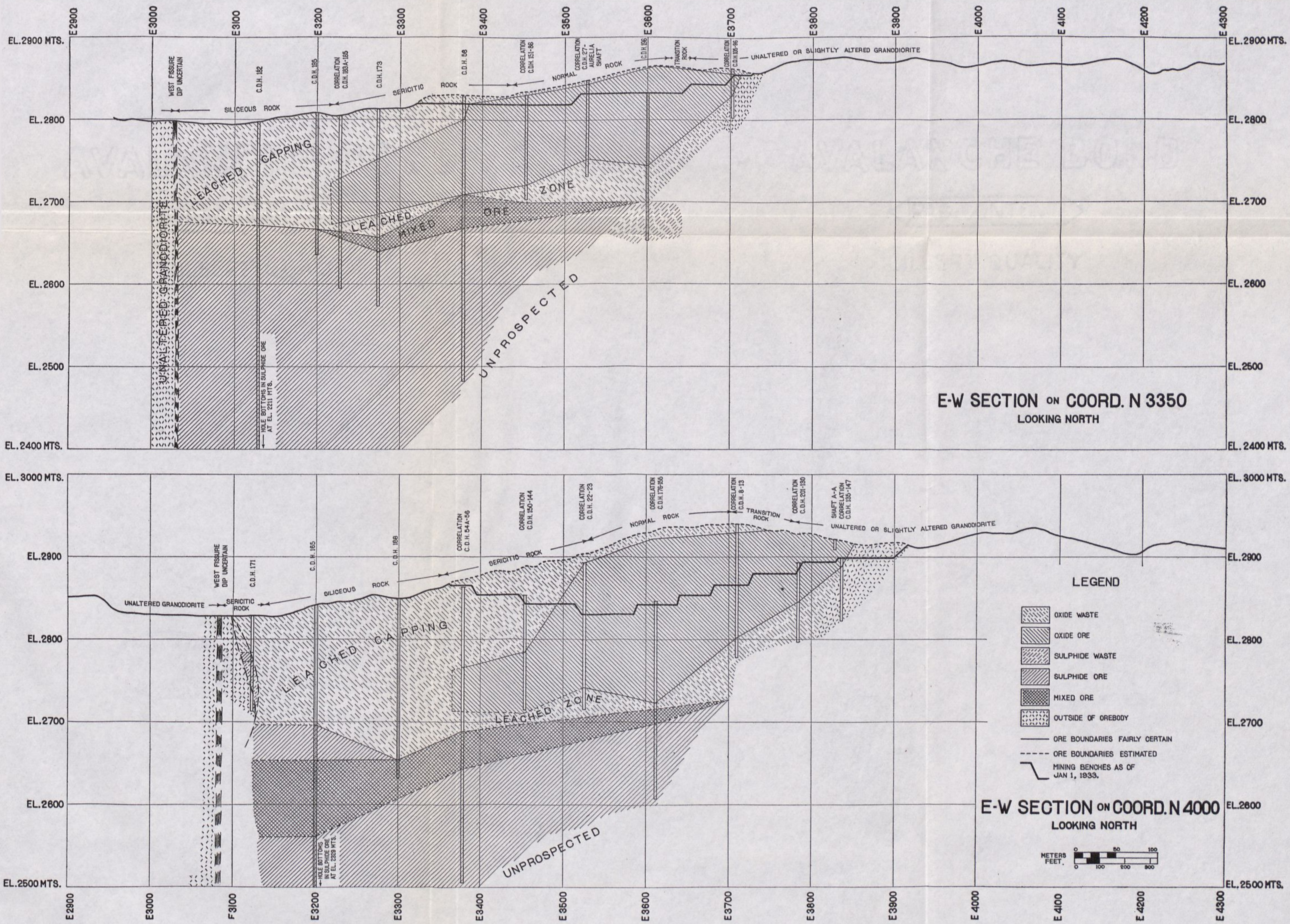
[4] March, W. S., Jr., personal communication.

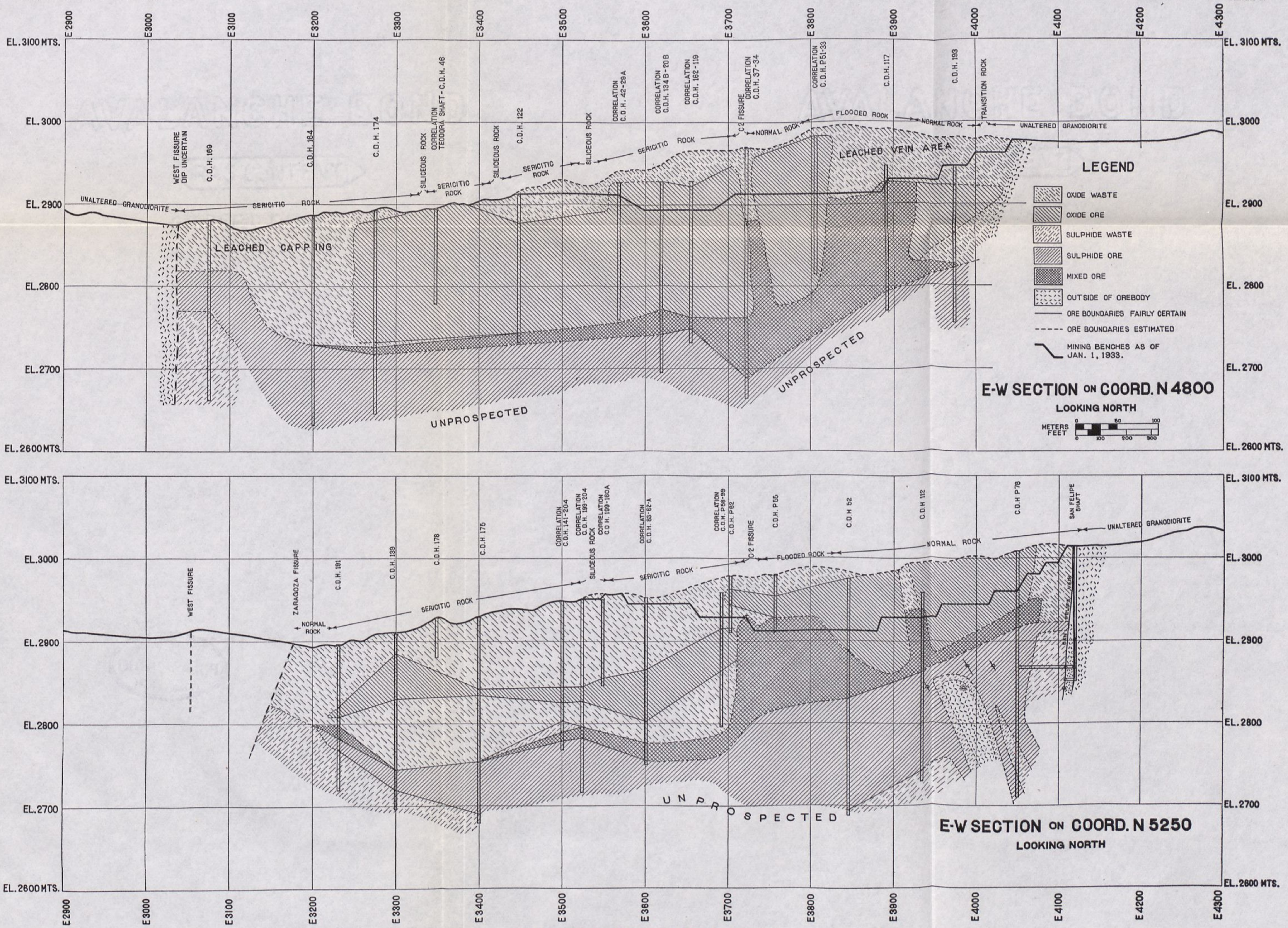
[5] Bandy, M. C., private report, 1932.



ORE DISTRIBUTION AT CHUQUICAMATA



CROSS SECTIONS OF CHUQUICAMATA ORE BODIES



CROSS SECTIONS OF CHUQUICAMATA ORE BODIES

These cuttings show that the ore at this depth has been secondarily enriched. The original sulphide minerals which came in with the quartz were pyrite (60 percent of the sulphide minerals) and enargite (25 percent). The enargite has been replaced and enriched by supergene chalcocite (12 percent), and the chalcocite by covellite (3 percent).

This shows that enrichment has taken place to a depth of more than 585 meters below the surface. This extreme depth of enrichment indicates that there were periods when the water table must have been at considerable depths, or the circulation below the water table was so active that the copper-bearing meteoric waters were able to carry the copper in solution to great depths before encountering favorable conditions for precipitation.

Throughout the mine, in the flooded rock and in the narrow veins of the Northeast fissure zone and east of the E-1 fissure, the top of the sulphides occurs at a much higher level than in other parts of the ore body. The mixed ores found on the present mine benches are in these localities. It is believed that these zones represent residual sulphides from the early enriched ore body, which, owing to the very low porosity of the rock, have not been oxidized to the extent of the surrounding rock.

The Northeast fissure zone area is substantially different from other parts of the mine in that toward the eastern limit of the ore body the veins pass down into practically unaltered rock, so that except for a thin blanket of chalcocite enrichment, the sulphide zone consists of a series of veins, with a few meters of adjoining mineralized rock and intervening unmineralized rock. The Panizo fissure zone consists of fissure veins in practically unaltered rock. However, westward from coordinate E. 400 in this area, disseminated copper minerals between the veins begin to appear and the tenor increases toward the C-2 fissure. This is true in both the oxide and the sulphide zone. The veins themselves are generally more deeply leached than the intervening rock, and the transition to sulphides is accomplished in much less vertical distance. In general, the veins in this area will show as much as 75 meters of leached zone composed of predominant yellow iron sulphate with other oxides and sulphates. This will pass into a zone from 10 to 50 meters thick of brochantite, chalcanthite, chalcocite, and pyrite, and within a few meters the primary minerals, enargite, covellite (?), sphalerite (very minor), and chalcopyrite (very rare) will appear. With further depth the veins consist of practically barren pyrite. A certain amount of enrichment has occurred to the depths thus far reached (250 meters), gradually lessening with depth.

Genesis and history of the ore deposit

As many points connected with the genesis of the deposit have been given in the preceding pages, a general outline of the events that are believed to have been involved in the formation of the present ore body will suffice at this point.

1. Intrusion of the granodiorite at the end of the Mesozoic or early in Tertiary time.

2. Extensive fracturing and shearing, which produced first the West and Zaragoza fissure zones and subsequently the Cabo Fierro, C-2, Ines, and Teodora fissure zones.

3. Heavy silicification of these fissure zones, with sericitization and lesser silicification of the adjoining areas.

4. Another period of fissuring with attendant crushing and shearing of the Cabo Fierro zone and formation of the Northeast fissure zone by the action of a shearing couple between the C-2 fissure and the Panizo fissure zone. Also, development of the E-1 and Balmaceda fissures. Very little fracturing between the Cabo Fierro, Teodora, and Ines zones and the West and Zaragoza fissures.

5. Introduction of quartz and primary copper, with the strongest deposition in the highly fractured siliceous zone that fades out to the east and west. The wedge between the Cabo Fierro, Teodora, and Ines fissures and the West and Zaragoza fissures was not heavily mineralized, owing to less fracturing in the last fracture period and possibly to faults along the west side of the Cabo Fierro fissure that acted as a dam to the solutions.

6. A long period of leaching under the damp climate of the middle Tertiary, with deep enrichment, especially in the siliceous areas. Formation of an enriched ore body completely covered with leached capping.

7. Pliocene uplift and change to a dry climate. Probable small movement along all fissures and general weak northeast and northwest fracturing throughout the deposit.

8. Erosion from Pliocene to Recent time which removed most of the capping over the ore body. Torrential storms provided sufficient precipitation to cause complete leaching of the fractured siliceous zone and the area between the Cabo Fierro and West fissures, the leaching keeping pace with erosion and further enriching at lower levels the primary ore body of the siliceous zone. Partial leaching and deep oxidation of the area east of the siliceous zone formed the brochantite ore body and slightly enriched the sulphide ore beneath. Formation of the leached zone between the brochantite and sulphide ore by fluctuating water table and leaching of the old protore zone farther east.

9. Periods of decreased rainfall in recent times, causing the water table to be depressed at intervals, resulting in oxidation of the top of the sulphides, in places to considerable depth. Continued oxidation of the upper part of the ore body.

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3. Willis, Bailey, Studies in comparative seismology—Earthquake conditions in Chile: Carnegie Inst. Washington Pub. 382, 1929. Sets forth the geomorphology and general geology of various parts of Chile, including a brief study of the Chuquicamata district.

CHUQUICAMATA MINE, CHUQUICAMATA, CHILE.

Ore deposits at Potrerillos, Chile

By W. S. March, Jr.[1]

Chuquicamata, Chile

Introduction

Geography.—The Potrerillos deposits of the Andes Copper Mining Co. lie in the Province of Atacama, Department of Chanaral, Chile, 94 miles by railroad from the port of Barquito. (See fig. 55.) The nearest settlement is Pueblo Hundido, a town of 1,000 inhabitants, 60 miles distant, at the junction of the Potrerillos Railway and the main line of the Chilean Railway system.

The district is situated in the midst of the barren Atacama Desert, whose aridity is broken only by occasional snows and rains from May to July. Strong winds are prevalent, and the temperature ranges between 24° and 71° F., with a mean for the year of 54° F.

Topographically the immediate mine area is moderately rugged. The mine workings have an average altitude of 10,500 feet in a narrow valley between outlying spurs of the western range of the Andes. The neighboring peaks reach altitudes of 15,000 feet.

History.—According to the old records, no claims were denounced in the district prior to 1894. From that year to 1913, when William Braden acquired most of the existing claims, the richer seams and veins of the deposits were worked by primitive methods, and the sorted ores were carted to Pueblo Hundido. Mr. Braden, after partly developing the property, sold it to the Andes Copper Mining Co. in 1916, and this company placed it on a producing basis in December, 1926. The combined capacity of the plants is now 230,000,000 pounds a year.

General geology

Geomorphology

The topographic forms about the Potrerillos area are widely separated, sharp divides; maturely eroded rolling hills having a relative relief of several thousand

[1] Thanks are due to Mr. E. F. Reed, of Potrerillos, for his assistance in preparing this paper.

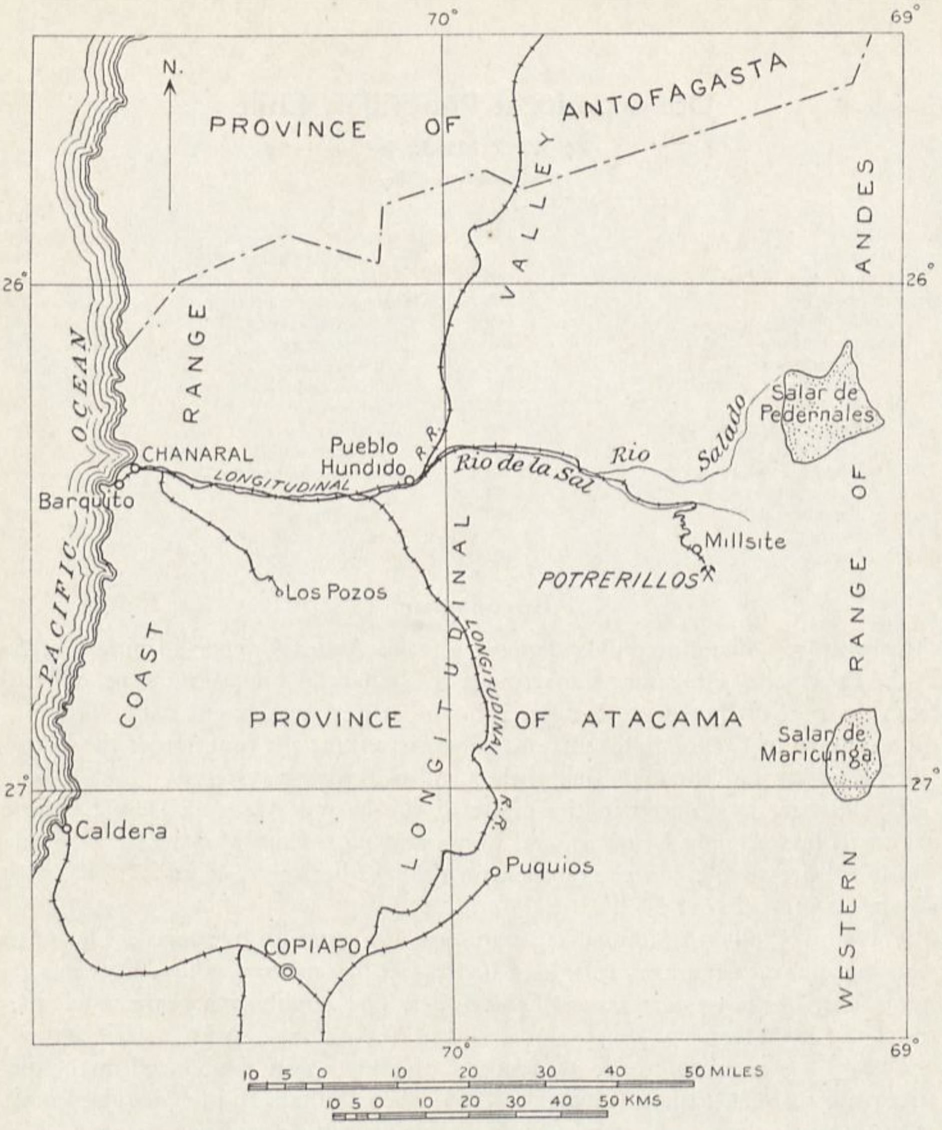


FIGURE 55.—Index map showing location of Potrerillos, Chile. (By W. S. March, Jr.)

feet; broad, flat plateaus; and level gravel-filled valleys in which are deeply incised youthful canyons.

So far as known the divides, hills, plateaus, and wide valleys are remnants of an old mature land that developed under conditions of moist climate and deep rock decay, in the period that intervened between the uplift of the area above the sea in late Upper Cretaceous or early Tertiary time and its subsequent uplift in the Pliocene (?). After the later uplift the climate became more arid, and the products of the previous rock decay were swept, during Pliocene or early Quaternary time, into the broad valleys and were there deposited to form the coalesced fans of the existing piedmont alluvial plains. Probably in the Pleistocene another uplift began, which has continued to the present. Attendant on this uplift the climate became substantially the same as it is now, and the streams began to cut their present youthful canyons.

This geomorphic cycle has had an important influence upon the Potrerillos deposits. The moist climate and mature land development of the early and middle Tertiary caused the concentration of the copper in a deep zone of enrichment. When the conditions changed to a drier climate and rejuvenated topography, in Pliocene to Recent time, erosion began to strip off the leached portions of the deposits and, as the water table receded, to expose the old zones of sulphide enrichment to oxidizing conditions. The precipitation of this period, however, was not sufficient to leach appreciable amounts of the copper from the oxidizing zones and reconcentrate it in new sulphide zones. As a consequence of this cycle, the oxide ores of the present deposits are the oxidized equivalents of the upper parts of the old secondary sulphide zones, and most of the sulphide ores are the slightly reenriched equivalents of their roots.

Rock formations

General sequence.—Plate 31 shows the areal distribution of the different formations surrounding the deposits in so far as they have been determined.

Apparently, a shallow inland sea covered this area from Jurassic to early Upper Cretaceous time, and in this sea the marine sediments of the Potrerillos formation were deposited. This period of deposition was ended by the first of the Andean uplifts, which was accompanied by minor volcanism and probably by the intrusion of melaphyre in sills and masses. In the retreating sea of this time the beds of the Cerro Negro formation were laid down. In late Upper Cretaceous or early Tertiary time the area was finally elevated above the sea and strongly folded and faulted, and igneous activity began on a larger scale. After the emergence of the area erosion removed parts of the Cerro Negro formation, and on the dissected surface thus produced a great thickness of early Tertiary andesitic volcanic rocks was deposited. These were succeeded by rhyolitic intrusives, flows, and explosion breccias. Toward the end of this epoch of mountain building and igneous activity of early Tertiary time the Cobre porphyry was intruded and the ore deposits formed. The succeeding formations are not shown on the map. They are thin deposits of gravel which originated after the Pliocene and the Pleistocene to Recent uplifts and remnants of Pleistocene glacial deposits.

Potrerillos formation.—Recent work has shown that the Potrerillos formation is divisible into three or more units, but owing to the incompleteness of this work it is considered here as a single unit. From top to bottom it comprises the following beds. The figures indicate the maximum observed thicknesses.

	Feet
Fossiliferous thin-bedded to massive granular blue-gray limestone with a few arkosic members	590
Highly fossiliferous brownish to yellowish sandy shale containing large ammonites near its base; generally the host of the melaphyre sills	362
Thin-bedded blue impure granular limestone with shaly and arkosic members; fossils not abundant	525

Separating the formation from the overlying Cerro Negro is a bed of limestone and quartz conglomerate which marks an unconformity of unknown magnitude.

Melaphyre.—The melaphyre generally occurs as sills in the shaly members of the Potrerillos formation. It is brownish to grayish black and ranges from a rock of diabasic texture to one having an almost glassy groundmass with a few small plagioclase phenocrysts. In places the upper parts of the sills have orbicules filled by quartz and calcite.

Cerro Negro formation.—The rocks of the Cerro Negro formation and their maximum observed thicknesses are listed below.

	Feet
Thin-bedded green limy sandstone and limestone at the base, passing into red sandstone largely derived from andesitic debris; rarely fossiliferous	722
Gray fine-grained limy shale with limestone members; locally fossiliferous	197

Parts of this formation have been completely eroded, and a large unconformity separates it from the succeeding andesitic rocks.

Andesitic volcanic rocks.—Only the lower part of the andesitic rocks has been studied. It consists of the following members:

	Feet
Green to reddish-purple flows and breccias of hornblende andesite and interbedded continental derivatives	500
Dark-reddish andesite flow conglomerates with rounded to subangular fragments of andesite, melaphyre, and sediments	164

Rhyolitic volcanic rocks.—The rocks of rhyolitic composition occur as dikes, flows, and breccias. Except in the extreme northwestern part of the area, where the thickness of dikes and flows is unknown, this formation is represented by explosion breccias filling small volcanic necks or vents. In general the breccias are light-gray rocks consisting of small angular fragments of sediments, melaphyre, andesite, rhyolite, and occasionally diorite in a rhyolite matrix.

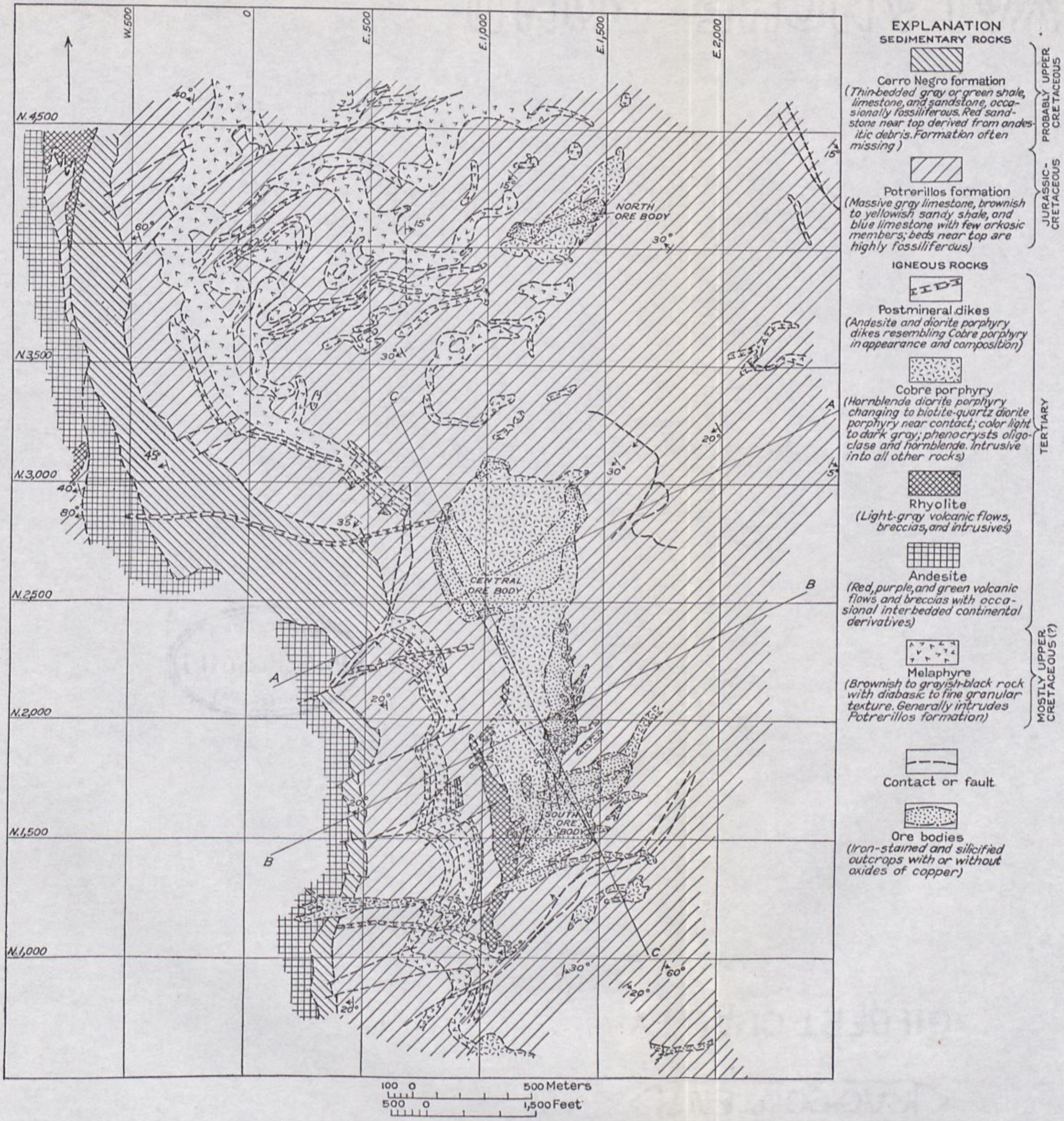
Cobre porphyry.—The Cobre porphyry intrudes all the preceding formations as dikes, sills, and small stocks. The stocks contain practically all the ore deposits of the area, the largest ones in an elongated pear-shaped stock having a maximum length of 5,800 feet and a width of 2,040 feet.

The rock varies from greenish to dark gray and consists of oligoclase, hornblende, or biotite phenocrysts in a fine-grained groundmass of quartz, feldspar, and ferromagnesian minerals. In composition it ranges from a hornblende diorite porphyry in the central parts to a biotite-quartz diorite porphyry near the boundaries.

Surrounding the principal porphyry stock is a halo, 500 feet or more thick, in which the sediments have been largely converted to a rock containing the contact silicates garnet, wollastonite, enstatite, diopside, epidote, zoisite, clinozoisite, and tremolite. In addition it contains some pyrite and a little specular hematite, which may have originated through the same contact metamorphism.

Postmineral dikes.—The dikes of postmineral age consist of andesite and diorite porphyry which megascopically cannot be distinguished from the Cobre porphyry and appear to be related to it. In a few places they cut the ore bodies.

Gravel.—Throughout the area, in the valley and gulch bottoms, are thin deposits of loosely consolidated fluvial gravel.



GENERALIZED SURFACE GEOLOGY AT POTRERILLOS MINE, CHILE

For sections along lines *A–A*, *B–B*, *C–C*, see figures 57–59.

Structure

Broadly the Potrerillos area has the following structural elements: An asymmetric anticline, a porphyry stock intruded into the west flank of the anticline, and faults of three ages.

The sediments of the Potrerillos formation, the melaphyre, and the volcanic rocks have been folded into an anticline whose axis strikes about N.10° E. and pitches at a low angle to the southwest. Its west limb dips 30°–70° W., and its east limb inclines gently to the east. Apparently the steeply dipping west limb constituted a plane of structural weakness, for it undoubtedly guided the porphyry intrusive to its present position.

The three ages of faulting were pre-andesite, pre-porphyry, and post-porphyry. Faults of pre-andesite age strike about due north and dip steeply to the west or strike northeast and dip at low or moderate angles to the northwest. Most of the northerly system are thrust faults, and two of them, one along the western edge and one just east of the mapped area, have a large but unknown displacement. The faults of the northeasterly system generally show a horizontal displacement of the strata to the right, which may be as much as 1,640 feet. Because of their relations to the thrust faults, they are thought to represent a tear faulting that accompanied the thrusting. The next period of faulting occurred after the eruption of the andesitic and rhyolitic rocks but before the porphyry intrusion. This faulting appears to have taken place mainly by movement along the existing pre-andesite faults, and as displacements greater than 300 feet have not been noted, it would appear to have been relatively minor. The last period of faulting began after the intrusion of the Cobre porphyry and is discussed under "Ore deposits."

These data indicate that most of the folding and the major part of the faulting must have taken place in the interval between late Upper Cretaceous time and the intrusion of the Cobre porphyry in the early Tertiary. This folding and faulting appears to have been the result of successive compressive forces acting from the west.

Ore deposits

The Potrerillos deposits comprise three ore bodies, but as the north ore body has been explored only by a few diamond-drill holes and the south ore body is practically unexplored south of coordinate 1600 N. and east of coordinate 1300 E., the following detailed description is limited to the developed parts of the south and central ore bodies.

Form and structure

In plan and section (see pl. 31 and figs. 56, 57, and 59) the central ore body is extremely irregular and is best described as a rudely crescentic body that faces the north and has a wedge-shaped section. This wedge decreases in width from the surface downward and stands almost vertical. The ore body reaches its maximum dimensions on the intermediate haulage level, where it attains a length from tip to tip of 2,000 feet and a width of 1,115 feet. Diamond drilling has proved the continuity of the ore to a depth of 1,510 feet below the surface.

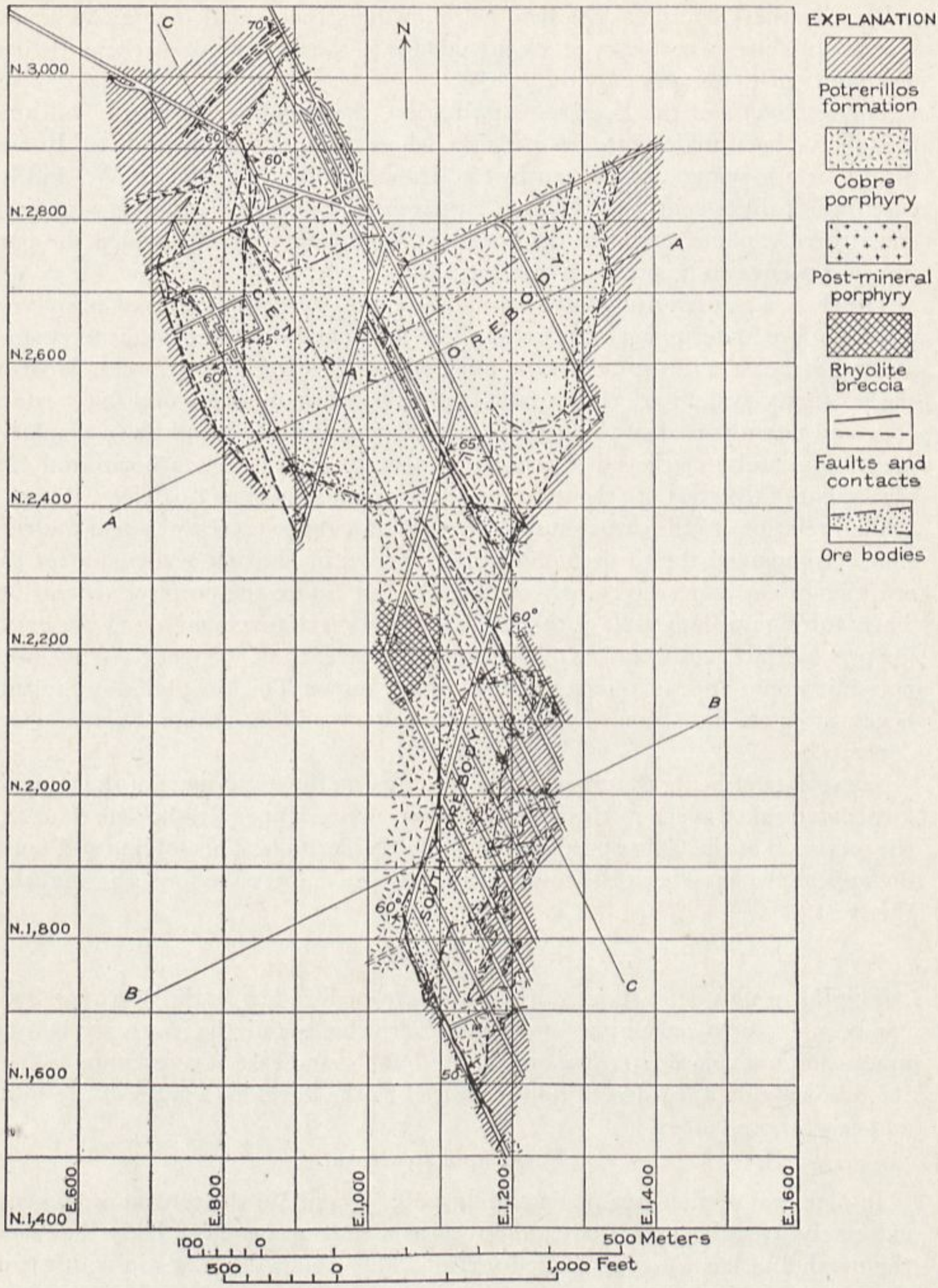


FIGURE 56.—Geologic plan of intermediate haulage level, Potrerillos mine. (By W. S. March, Jr.) For sections along lines A–A, B–B, C–C, see figures 57–59.

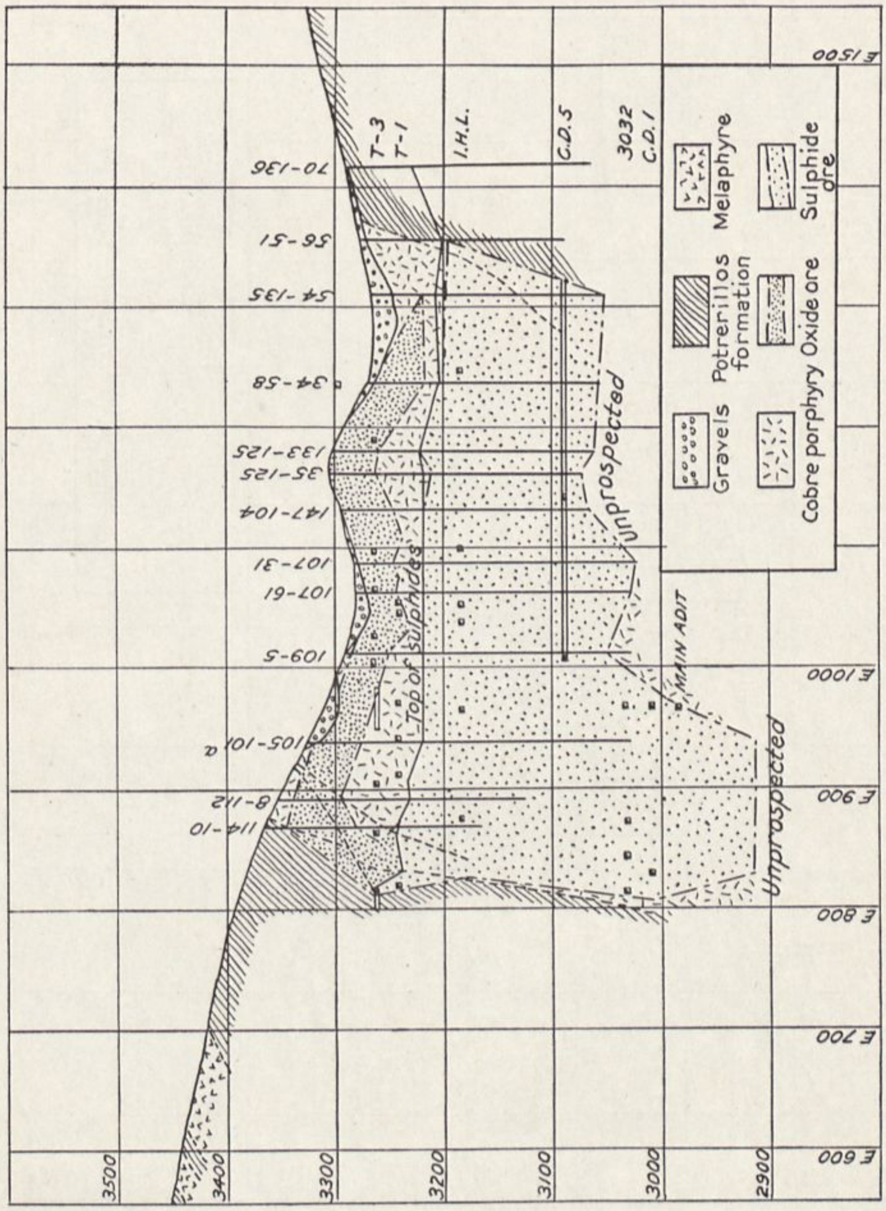


FIGURE 57.—Section along line A–A, figure 56, showing generalized geology of central ore body, Potrerillos mine. (By W. S. March, Jr.)

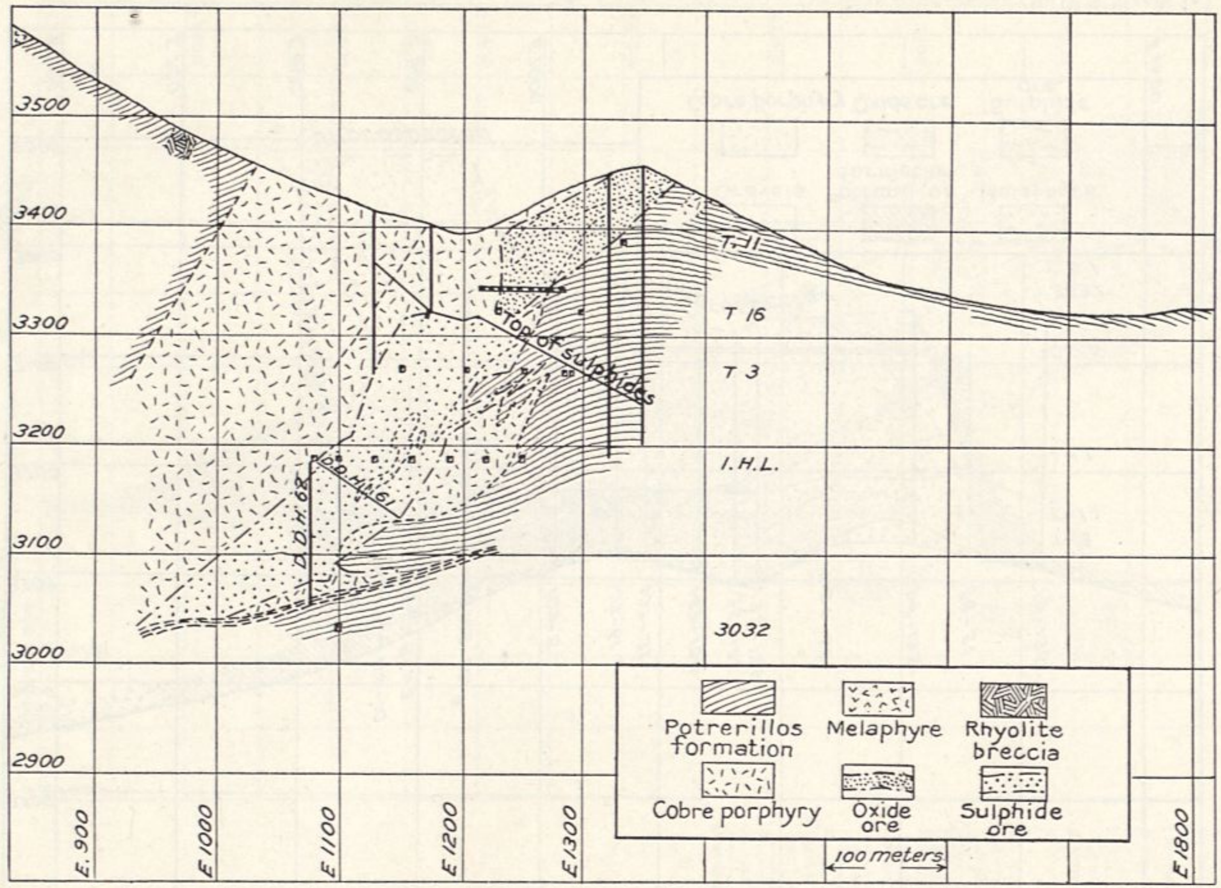


FIGURE 58.—Section along line B–B, figure 56, showing generalized geology of south ore body, Potrerillos mine. (By W. S. March, Jr.)

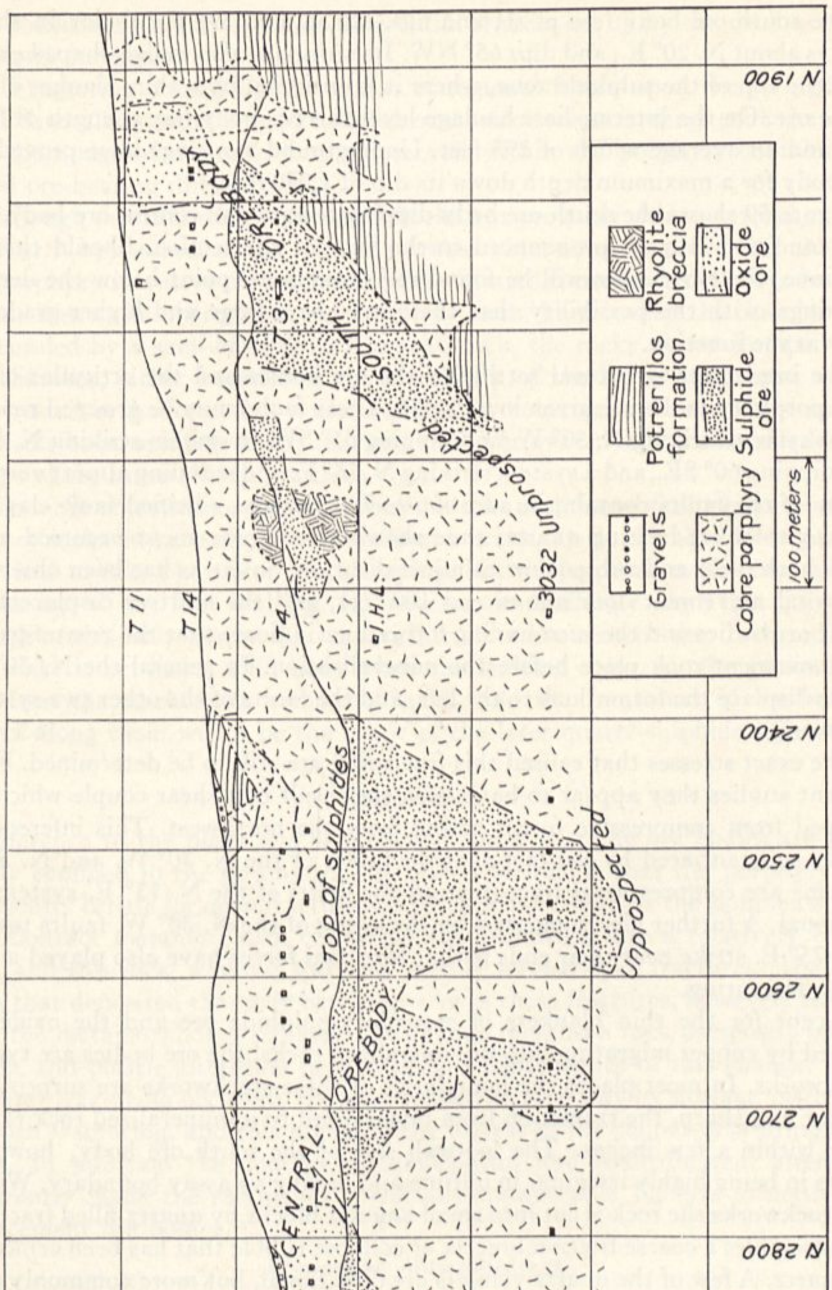


FIGURE 59.—Generalized section along line C–C, figure 56, showing relations between central and south ore bodies, Potrerillos mine. (By W. S. March, Jr.)

The south ore body (see pl. 31 and figs. 56, 58, and 59) is tabular in shape, strikes about N. 20° E., and dips 65° NW. Its section is also wedge-shaped except near the top of the sulphide zone, where it is encircled by a thin blanket of sulphide ore. On the intermediate haulage level this ore body has a length of 1,650 feet and an average width of 295 feet. Underground workings have proved the ore body for a maximum depth down its dip of 1,950 feet.

Figure 59 shows the south ore body dipping toward the central ore body, and this condition is more pronounced to the west of the section. Should this dip continue, the two bodies will be found to join at some point below the deepest workings, with the possibility that there may be a large and higher-grade ore body at the junction.

The immediate structural setting of the ore bodies and the attitudes of the post-porphyry faults are given in plate 31. These faults may be grouped roughly into a system striking N. 30° W. and dipping 65° SW., a system striking N. 5° E. and dipping 60° SE., and a system striking N. 75° E. and standing almost vertical. Many of the faults contain, in addition to fresh gouge, silicified fault clay and fragments of ore-bearing quartz, thus showing that movement occurred along them both prior and subsequent to mineralization. So far as has been observed, the total movement does not exceed 100 feet, and the relative displacements of the ore bodies and the surrounding formations indicate that the greater part of the movement took place before the mineralization. In general the N. 30° W. faults displace the formations to the left, and the faults of the other two systems to the right.

The exact stresses that caused this fracturing are still to be determined. From present studies they appear to have been the result of a shear couple which developed from compressive forces acting from the northwest. This inference is partly substantiated by the fact that the faults of the N. 30° W. and N. 5° E. systems are compressional fractures and the faults of the N. 75° E. system are tensional. A further idea suggested by the swing of the N. 30° W. faults toward a N. 75° E. strike near their ends is that torsional forces have also played a part in the fracturing.

Except for the thin blankets of secondary sulphide ore and the oxide ore formed by copper migrating into unmineralized rocks, the ore bodies are typical stockworks. In most places the boundaries of these stockworks are surprisingly regular and sharp, the transition from mineralized to unmineralized rock taking place within a few inches. The footwall side of the south ore body, however, differs in being highly irregular in outline and having an assay boundary. Within the stockworks the rock is cut into small angular blocks by quartz-filled fractures and resembles a coarse friction breccia or collapse rubble that has been cemented by quartz. A few of the quartz veinlets are directional, but more commonly they strike and dip at all angles and cannot be traced more than a few feet.

Several hypotheses have been advanced to explain the highly fractured rock of the stockworks, but all of them are open to one or more objections. The principal hypotheses are as follows:

1. Shrinkage fracturing due to differential stresses set up by the cooling of the porphyry intrusive.
2. Fracturing caused by the action of regional forces upon the formations.
3. Mineralization stoping by hydrothermal solutions ascending trunk channels.
4. Slumpage of the rocks into a reservoir within the porphyry containing a liquid ore-bearing differentiate.

Although the fracturing of the stockworks was probably due to several causes, the fourth hypothesis meets with the fewest objections. It postulates that, as the porphyry intrusive crystallized, differentiation concentrated the ore-bearing liquids into a chamber within the porphyry mass. Later, when the chamber was surrounded by a shell of more or less solid rock, the rocks above slumped into the chamber, either because of the instability of the liquid base upon which they rested or because they were impelled by some other forces. In slumping the rocks became highly fractured, and the fractures served as channels for the escape of the mineralizing solutions.

The main objection to this hypothesis is that premineral faults pass from the country rocks into the stockworks without a break. To do this the faulting would have had to take place after the slumping, but this appears to be contradicted by the age of the first faulting. If, however, immediately after the slumping, enough of the early barren quartz was introduced to cement the fractured rock and make it act like a solid body when the faulting occurred, the faults could pass into the stockworks without a break, and the fragments of ore-bearing quartz along them would be the result of the later quartz-sulphide mineralization.

Occurrence

Reference to the plans and sections will show that the ore bodies are practically confined to the porphyry. The reason for this is that the porphyry was sufficiently brittle for open fractures to develop in it, whereas the sediments were not. Contact metamorphism converted the sediments into a relatively brittle rock, and this rock, where it slumped, readily formed open fractures. The solutions that deposited the early barren quartz in these fractures, however, reacted with the metamorphosed sediments to change them to a rock composed largely of soft and plastic alteration products. As a consequence of this change, when the later fracturing occurred, the rock tended to give way by flowage instead of by open fracturing, and this hindered the ingress of the copper-depositing solutions. In addition the contact metamorphism and hydrothermal alteration apparently made the sediments chemically unfavorable for the formation of replacement ore bodies.

Hypogene mineralization

Rock alteration.—Both in the stockworks and in the surrounding rocks hydrothermal alteration has been intense. In the stockworks sericitic alteration has changed the original rock minerals of the porphyry to quartz, sericite, and calcite and the metamorphosed sediments to sericite and chlorite. The plagioclase feldspars of the porphyry were more intensely altered than the orthoclase, and some pyrite has been formed from the breaking down of the ferromagnesian minerals to sericite. A short distance outside the stockworks the sericitic alteration gave way to a propylitic alteration, by which the ferromagnesian minerals of the porphyry were changed to chlorite, epidote, and calcite, the feldspars were changed to calcite and some sericite, and pyrite was formed. The sediments were similarly altered.

These alteration products form halos around the ore bodies not less than 300 feet wide, reaching their greatest thickness in the porphyry. A similar halo exists in the sediments near the porphyry contact and is represented on the surface by a bleached and iron-stained zone several hundred feet wide. Within this halo the sediments have been reduced to a soft, massive rock without a vestige of the original bedding.

Mineralogy.—The hypogene minerals occur as open fracture fillings and to a lesser extent as metasomatic replacement deposits. They are briefly described below.

Orthoclase occurs in veinlets and irregular masses replacing the rock minerals in the form of small pink crystals associated with quartz. It generally shows evidence of hydrothermal alteration and may be replaced by the sulphide minerals. Consequently, it is thought to be an end-product of the crystallizing porphyry which was introduced along fractures, rather than a mineral brought in by hypogene solutions. It is most abundant in the vicinity of the ore bodies.

Quartz occurs in clear to milky white crystals filling open fractures which are locally vuggy and replacing the rock minerals. It may accompany the sulphides and orthoclase or be cut by quartz-sulphide and calcite-dolomite-enargite filled fractures. It is found mostly within the ore bodies.

Calcite and dolomite occur usually as flesh-colored and white crystals with enargite filling small veinlets that cut the quartz-pyrite-chalcopyrite veinlets and are cut by the quartz-molybdenite veinlets. Their distribution is sparse and erratic.

Pyrite occurs as typical crystals, many of which are badly strained or crushed, disseminated through the rock and in the quartz veinlets. It is associated with the quartz and sulphides but more generally is cut by fractures filled with quartz and sulphides or calcite-dolomite-enargite. The pyrite is concentrated in the ore bodies and occurs also in aureoles just outside their boundaries.

Chalcopyrite occurs as brassy-yellow masses replacing the rock minerals and to a slight extent pyrite and in quartz-filled fractures. It may be present in veinlets associated with quartz or in seams which cut the quartz and pyrite and which in turn are cut by quartz, calcite, dolomite, enargite, and molybdenite. In many places it has been almost entirely replaced by enargite. It rarely occurs in appreciable amounts outside the ore bodies.

Enargite occurs in crystalline or massive form replacing the chalcopyrite, in veinlets associated with quartz or calcite-dolomite, and cementing fractures in the quartz-pyrite-chalcopyrite veinlets. It is cut by the quartz-molybdenite veinlets. Most of the gold and silver in the ore are contained in the enargite. It is found mainly within the ore bodies.

Tetrahedrite, sphalerite, and galena are rare minerals that have about the same occurrence and distribution as the enargite.

Molybdenite occurs with quartz in seams that cut all the preceding minerals. It is found in uniform but small amounts within the ore bodies and the neighboring country rocks.

Paragenesis.—The paragenesis of the hypogene minerals deposited from hydrothermal solutions derived from the porphyry intrusive was as follows:

1. Intense fracturing of the rock by slumping or some other cause tapping a reservoir containing the mineralizing solutions.
2. Introduction and formation of quartz, calcite, sericite, chlorite, epidote, pyrite, and possibly a little chalcopyrite. The quartz and alteration products continued to form in minor amounts throughout the succeeding mineralization.
3. Fracturing.
4. Introduction of quartz and chalcopyrite with a little pyrite.
5. Fracturing.
6. Introduction of quartz, pyrite, enargite, and small amounts of tetrahedrite, sphalerite, and galena. The period ended with the deposition of calcite, dolomite, and enargite.
7. Fracturing.
8. Introduction of quartz and molybdenite.

It is evident that the foregoing sequence was not the result of an orderly deposition from solutions but of successive waves of mineralization that followed recurrent fracturing.

Oxidation and ground water

Mineralogy.—In view of the limited scope of this article only the most abundant of the oxide minerals can be described. They occur filling fractures and disseminated in the rock and have the following form and distribution:

Chrysocolla, azurite, and malachite occur in the usual forms. They are generally found in the outcrops of the ore bodies or their immediate vicinity and fade out a short distance below the surface.

Tenorite and melaconite occur as grayish-black scales and earthy black masses. They have a distribution similar to the preceding minerals and are more abundant in the sediments than in the porphyry.

Brochantite occurs in blackish-green acicular crystals, drusy crusts, and massive bodies. It constitutes the principal ore mineral and is most common in a zone that begins just below the surface and extends almost to the top of the sulphides.

Cuprite occurs in blackish to deep-red cubes and massive bodies, just above and below the top of the sulphide zone, associated with chalcocite masses.

Native copper occurs in copper-red arborescent growths and sandy masses. Its distribution is similar to that of cuprite.

Limonite (generic term for all the iron oxides) occurs as maroon to seal-brown pulverulent grains, cellular boxworks, and iridescent black crusts filling the sulphide cavities, a brick-red to orange flooding of the rock, and an orange to brown stain along fractures. It is found in the outcrops of the ore bodies provided not much brochantite is present.

Sufficient is known about some of these oxide minerals to state briefly how they originated. Azurite and malachite, through the action of carbonated meteoric waters, formed from the alteration of brochantite. Brochantite resulted from the direct oxidation of chalcocite where ferric sulphate and sulphuric acid were present in sufficient amounts. Cuprite and native copper, however, formed from the oxidation of the chalcocite where the concentrations of ferric sulphate and sulphuric acid were low in the oxidizing solutions. Limonite was derived from the oxidation of the iron sulphide and in a few places by the action of ferric sulphate on brochantite.

Each sulphide upon oxidizing usually yields a distinctive type of limonite. In general it may be stated that the higher the ratio of copper to iron the more intensely maroon or seal-brown the limonite will be and the more it will tend to remain in the cast left by the oxidized sulphide.

Oxide zone.—In the central ore body (fig. 57) the oxide zone has an average depth of 260 feet, and in the south ore body (fig. 58) 360 feet. It is composed of three subzones—from the surface downward a leached zone, an oxide ore zone, and another leached zone. The tenor of the oxide ore in place is 1.65 percent.

The surface leached zone is erratically developed over the oxide ore and is shallow, rarely exceeding a depth of 50 feet. Near the contact between porphyry and sedimentary rock it practically disappears. The principal minerals in this zone are quartz, sericite, kaolin, chrysocolla, azurite, malachite, tenorite, melaconite, brochantite, and limonite. Considerable of the copper remaining in the leached zone is in the form of chrysocolla, azurite, malachite, tenorite, and melaconite, and these minerals serve to distinguish this zone. In addition, the rock is highly iron-stained and contains numerous sulphide casts partly filled by maroon and brown limonite. Another characteristic of this zone is that parts which have undergone intense primary sulphide mineralization can be distinguished by chemical analysis. Leaching has removed but little of the arsenic and silver introduced by the primary mineralization, and wherever the amount of these elements is relatively high, intense primary mineralization has occurred. By analyses and a study of the limonite types, the nature and grade of the sulphide mineralization under an outcrop can be roughly forecast.

Underlying the surface leached zone is the oxide ore zone. Its greatest thickness is adjacent to the contact between porphyry and sedimentary rock, where the ore extends from the surface to the sulphide zone. Away from the contact most of the copper is contained in brochantite; nearby, cuprite and native copper are also abundant ore minerals, but they give way to brochantite about 50 feet above the sulphide zone. Throughout the zone tenorite and melaconite are sparingly present, but azurite, malachite, and chrysocolla are found only where the zone crops out or along deep fissures. Limonite, also, may be practically absent if brochantite is abundant in the rock. The grade of the developed oxide ore is slightly higher than that of the sulphide ore. For this and other reasons the oxide ore is considered to be the oxidized equivalent of the upper parts of the enriched sulphide zones that formed under the developing mature land and moist climate of early to middle Tertiary time.

Separating the oxide ore from the sulphide is another leached zone which begins in the porphyry close to the sedimentary contact and increases in thickness toward the interior of the porphyry. It may attain a thickness of 165 feet. The principal minerals of the zone are quartz, sericite, brochantite, and limonite. How this leached zone originated is discussed in connection with the ground water.

Ground water.—The present top of the ground water (as determined by churn drilling) lies at an average altitude of 10,600 feet, is essentially flat, and in no way agrees with the top of the sulphide zone. In the central ore body the water table is both above and below the top of the sulphide zone, and in the south ore body it is an average of 295 feet below the sulphide zone. The top of the sulphides (fig. 59) has a pronounced tendency to follow the present topography, whereas the water table does not. Both from its altitude and from its tendency to follow the topography it is evident that the top of the sulphide zone was formed when the precipitation was heavier than at present and the water table stood at a higher level. Besides this, the sharpness of the transition between the oxide and sulphide zones shows that the water table must have been relatively stationary for a considerable period of time. Although no definite proof can be advanced, the top of the sulphide zone is thought to mark the position of the water table just before the first of the uplifts that began in the early Quaternary.

Various data indicate that the leached zone between the oxide and sulphide ores originated in a temporary stopping of the downward migration of the water table and sudden influxes of meteoric water from heavy storms, causing the water table to fluctuate between certain limits. The development of this leached zone began just before the early Quaternary uplifts and ceased in the south ore body after the first of these uplifts caused the water table to start receding again. In the central ore body, however, the position of the water table has not changed materially from that time to the present, and as a result the leached zone of this ore body has continued to develop until it is much more pronounced than that of the south ore body.

Supergene enrichment

Mineralogy.—Chalcocite, covellite, and bornite are the principal secondary sulphides, and they occur in typical forms replacing the primary sulphides. Chalcocite is by far the most abundant and occurs mainly near the top of the sulphide zone, for in depth it is succeeded by covellite and bornite. It has replaced the primary sulphides enargite, chalcopyrite, and pyrite, in the order named. As a consequence of this preferential replacement, enargite is lacking and chalcopyrite is sparingly present near the top of the sulphide zone. Covellite and bornite are rarely prominent ore minerals and occur mostly as films coating the primary sulphides.

Sulphide zone.—So far as it has been developed the sulphide zone in the ore bodies proper consists of a strongly enriched zone and a zone of moderate to slight enrichment. The tenor of the sulphide ore in place is 1.43 percent. In the central ore body the zone of strong enrichment terminates somewhat abruptly about 300 feet below the top of the sulphides, and in the south ore body about 325 feet. The principal sulphides of both zones are chalcocite, chalcopyrite, and pyrite, with most of the copper as chalcocite. Below the zone of strong enrichment the sulphide minerals are chalcocite, chalcopyrite, enargite, covellite, bornite, and pyrite, with most of the copper occurring in the first three. This zone of moderate to slight enrichment is lower in grade than the oxide ore zones.

Because of their somewhat abrupt termination and higher grade, the zones of strong enrichment are considered to be the slightly reenriched roots of the secondary sulphide zones that were formed in early to middle Tertiary time. The moderate to slightly enriched zones below their roots, however, may have originated largely in the period from the Pliocene to the present time by the deposition of the copper leached from the developing oxide ores.

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El cobre en el Perú

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Historia

Los abundantes utensilios y ornamentos de cobre encontrados en las ruinas preincaicas e incaicas, revelan que la población indígena del Perú extrajo ese metal desde antes del año 1000. Pero no sólo conoció la manera de aprovechar los minerales de cobre nativo y especies oxidadas, sino que también supo beneficiar las sulfuradas y obtuvo también bronce de temple de acero cuya secreta fabricación nunca ha sido descubierta por la civilización europea (Prescott). El tratamiento metalúrgico seguido para obtener el cobre era el de fundición en pequeños hornitos llamados "huayras"; y el metal llegó a tener una pureza superior a 99 por ciento de fino. La circunstancia de haberse encontrado en la superficie abundantes especies oxidadas (Chuquicamata) y de cobre nativo (Corocoro), contribuyó favorablemente al desarrollo de su industria.

Como los españoles importaron el fierro, que para la época era de más ventajosa aplicación que el cobre, en los tres siglos de la dominación hispana desapareció prácticamente su laboreo. Al mismo tiempo el descubrimiento de grandes yacimientos de plata (Potosí, Cerro de Pasco, Hualgayoc, etc.) influía poderosamente en el empleo de este metal para sustituir el cobre en los artefactos y ornamentos.

En los primeros 75 años de la era republicana (1821–96), la situación no cambió en lo menor. Tan sólo al terminar el siglo XIX, es que el Perú comienza a figurar como país productor de cobre, produciendo ya en 1901 10,000 toneladas de metal. Entre 1896 y 1902, se produjo 36,280 toneladas métricas (1); y se puede calcular que la producción total, desde 1821 (año de la Independencia) hasta 1902 inclusive, fué de 40,000 toneladas. En 1903 se estableció la Estadística minera oficial; y solamente a partir de ese año, es que se cuenta con datos precisos sobre la producción anual del país.

Producción

De conformidad con los datos estadísticos y las estimaciones más aproximadas, podemos consignar el siguiente cuadro (2), que resume la producción total de cobre del Perú durante la época de la república, es decir desde 1821 hasta 1932:

Producción de cobre del Perú, en toneladas métricas, 1821–1932

1821-1902	40,000	1913	27,776	1924	33,938
1903	9,497	1914	27,960	1925	36,864
1904	9,504	1915	34,727	1926	43,482
1905	12,213	1916	43,078	1927	47,758
1906	13,474	1917	45,176	1928	53,028
1907	20,482	1918	44,414	1929	56,115
1908	19,854	1919	39,230	1930	48,276
1909	20,068	1920	32,982	1931	46,094
1910	27,374	1921	33,283	1932	21,515
1911	27,735	1922	36,408		
1912	26,969	1923	44,166		1,022,930

Como se puede estimar en cerca de 4,500 toneladas la producción correspondiente a las épocas anteriores a la Independencia, no se está pues muy lejos de la verdad al indicar que del territorio peruano, se ha extraído en total hasta la fecha la cantidad de 1,000,000 toneladas métricas de cobre en números redondos.

Síntesis geológica del Perú

Una ojeada sobre una carta orográfica de Sudamérica basta para darse cuenta de que el Perú no constituye sino un tramo de una extensión mayor, recorrida en toda su longitud por la cordillera de los Andes. Como los rasgos orográficos derivan de los geológicos, la unidad geológica de toda aquella enorme extensión es un hecho que se comprueba con los nuevos descubrimientos.

Los Andes no constituyen, como algunos han creído, un geoanticlinal sencillo y moderno. Su estructura es más compleja de lo que parece y su edad mayor de lo que en un principio se consideraba. Donde se puede ver mejor esto, es en el territorio del Perú. Cuando se recorre el país de oeste a este, se observa un sensible paralelismo de varias cadenas de altas montañas que a veces se unen para formar nudos, como el de Pasco en el centro y Vilcanota en el sur. Estas tres cordilleras se denominan "Occidental," "Central" y "Oriental" y cuando se separan llegan a distar algunas decenas de kilómetros. La Cordillera Central constituye el divortium aquarum continental y de ella nacen los ríos que van al Pacífico y al Atlántico cortando las cadenas laterales por angostos y profundos cañones que llegan a tener más de 2,000 metros de profundidad. Algunos valles se inician en los nudos y corren longitudinalmente entre las tres cordilleras (3). En el Perú setentrional, los Andes son más bajos (3,000 á 4,000 metros) y virgan hacia el oriente amazónico o el Pacífico (4).

La faja que queda al este de la Cordillera Oriental se denomina en el país "Montaña" y constituye la alta selva amazónica. La faja comprendida entre las tres cadenas y sus altos declives o cordillerana, se denomina "Sierra"; y la angosta, litoral, que linda con el Pacífico, se conoce con el nombre de "Costa." Es en latitudes meridionales de esta zona donde los geólogos reconocen la existencia de otra cadena que denominan "Cordillera de la Costa" (5).

La obra clásica de De Martonne (6) contiene datos sobre la climatología de nuestro territorio, pero se incurre en la omisión de la zona de clima alpino que corresponde a nuestra Sierra Alta (más de 3,500 metros), pues en el planisferio exhibido en ella se considera uniformemente los Andes con un clima de tipo mediterráneo, colombiano (que debería denominarse mejor "semicordillerano").

Las cordilleras Oriental y de la Costa son las más antiguas, pues según parece estuvieron emergidas en su mayor parte desde el Mesozoico, mientras que las Central y Occidental sólo emergieron en el Cenozoico. Los geosinclinales paleozoico y mesozoico se formaron en un mar interior comprendido entre el viejo macizo precámbrico brasilero y el macizo similar que Steinmann denomina "de la Costa Pacífica."

Parece también que la Cordillera Central se levantó en época anterior a la Occidental, pues según Olsson (7) se observa una migración este á oeste en los ejes de los distintos plegamientos cordilleranos a través de los tiempos geológicos; es decir, que las cordilleras occidentales son más recientes que las orientales, excepción hecha de la litoral.

Los distintos movimientos epirogenéticos que han producido el levantamiento andino en el Mesozoico y el Cenozoico, estuvieron acompañados de intrusiones y extrusiones de rocas ígneas que afloran en grandes áreas observables sobre todo en la Cordillera Occidental en forma de batolitos y tobas volcánicas.

Durante el Cuaternario, sigue observándose todavía el levantamiento, que se revela por la emersión de grandes bloques de terciario marino en el departamento de Piura y la provincia litoral de Tumbes por el litoral norte y en el sur en la faja costanera de los departamentos de Ica y Arequipa. Durante esta era y conjuntamente que emergían los bloques de terciario indicados, parece que se produjeron notables inmersiones que se pueden localizar en la zona comprendida entre las penínsulas de Paracas y de Illescas.

Geología económica

Son relativamente raros los yacimientos del país que pueden calificarse como exclusivamente cupríferos, pues la plata, el plomo, el zinc y el oro forman generalmente parte tan importante del valor de sus minerales que se hace difícil indicar la especie económicamente dominante.

La mayor o menor pureza en cobre de los rellenos, guarda indudablemente relación con la profundidad del yacimiento originario, que la denudación ha barrido en el curso de las edades geológicas; pareciendo, que en los yacimientos en que la denudación ha logrado que se ofrezca visible su parte profunda, la mineralización cobriza predominase.

Provincias metalogénicas.—La existencia de provincias metalogénicas parece evidente, no obstante de que su distinción se dificulta por la falta de estudios metódicos detallados y por la invasión de las áreas en que geográficamente se distribuyen en el país. Se puede reconocer a nuestro juicio los dos tipos de mineralización cobriza que siguen:

Tipo cordillerano: Se distingue por los caracteres siguientes: (1) Presencia de mineralizadores argentíferos como el arsénico, antimonio, bario y manganeso; (2) presencia de plomo y zinc; (3) presencia de sulfoarseniuros de cobre (enargita y tetraedrita); (4) insignificante contenido de oro, que aumenta sensiblemente en profundidad y apreciable en plata; (5) repartición geográfica predominante en la Cordillera Central con ramificaciones que se extienden a las Occidental y Oriental; (6) edad terciaria reciente, pues atraviesa los estratos más modernos de la cordillera.

Tipo costanero: Cuyos caracteres son (1) ausencia de mineralizadores argentíferos; (2) ausencia de plomo y zinc; (3) ausencia de sulfoarseniuros de cobre y representación única de combinaciones sulfuradas simples (chalcosina, bornita y chalcopirita); (4) contenido apreciable de oro en contraste con baja ley o ausencia de plata; (5) repartición predominante en la costa, particularmente al sur del Callao; (6) edad que puede atribuirse al cretácico más reciente, pues no atraviesa las formaciones eocénicas litorales y parece realizarlo con las más recientes del senónico.

La provincia cordillerana se extiende a lo largo de los Andes peruanos en una faja de más de 100 kilómetros, bisectada por la línea de cumbres de la Cordillera Central. Al llegar al Ecuador desaparece, pero se extiende por el suelo de Bolivia con un ligero desplazamiento hacia el este de la línea orográfica de cumbres.

La provincia costanera invade buena parte de la cordillerana, dando lugar a que sea difícil distinguir yacimientos de uno y otro tipo. Su mayor representación la tiene en la zona litoral del sur del Perú y norte de Chile, desde Arequipa hasta Santiago de Chile. Se observa también en ella la desviación oriental anotada al tratar de la cordillerana y que da lugar a que los yacimientos de Chile disten más del océano que los yacimientos peruanos del mismo tipo (caso de El Teniente, etc.).

Distribución zonal.—La distribución zonal se observa bastante bien en los yacimientos del tipo cordillerano, porque en ellos la oxidación superficial ha sido pequeña y grande la profundización de los laboreos. Es así que en las partes altas de las fracturas originarias se comprueba la existencia de metales y combinaciones más volátiles que en sus partes profundas. Consecuencia de esto es el enriquecimiento de cobre en profundidad y que ha dado lugar a confundir este tipo de mineralización con el de carácter costanero.

La zona de oxidación en los yacimientos de este último tipo es muy extensa y al mismo tiempo podemos decir que las exploraciones no muy profundas realizadas en ellos no dejan entrever sino muy ligeras variaciones; tales son la disminución de la ley de cobre y el incremento de pirita y cuarzo con ley apreciable en oro sustituyendo a la chalcopirita y la chalcosina de las partes superiores.

Estructuras.—Todas las diversas estructuras conocidas, como son filones, vetas, sustituciones metasomáticas laterales e impregnaciones, se encuentran representadas en los yacimientos correspondientes a las dos provincias metalogénicas, siendo especialmente observables las impregnaciones en los yacimientos del tipo costanero como en Cerro Verde, Quequeña, Tiabaya, Ferrobamba, Quellabeco, Toquepala, Ilo, etc.

Las sustituciones metasomáticas son casos frecuentes en las calizas y tobas, donde llegan a formar ensanchamientos y depósitos interestratificados de valor, como son algunos de Morococha y Cerro de Pasco, etc.

Criterio termometalogénico.—Los yacimientos cordilleranos comprenden minerales de alta, media y baja temperatura; siendo frecuente que la denudación de los Andes muestre en la superficie actual las especies de temperaturas moderadas y rara vez las de alta. Las fracturas mineralizadas de esta provincia metalogénica son con frecuencia de una gran constancia vertical, habiendo en tiempo de su formación llegado hasta muy cerca de la superficie y depositado allí especies argentíferas y plomosas.

En la provincia costanera no se conoce las especies de baja temperatura, pero tampoco abundan las de extremo carácter opuesto.

Como los yacimientos cordilleranos han sido los más reconocidos en profundidad, se puede hablar de la constancia vertical de su mineralización (Casapalca, Alpamina, Cerro de Pasco). Igual afirmación, pero con reservas, puede hacerse en lo que respecta a la provincia costanera.

Enriquecimiento.—La oxidación de los yacimientos peruanos es notable en la zona geográfica de la provincia costanera, en donde se extiende varias centenas de metros bajo la superficie, a causa de que en la zona desértica de la vecindad del Pacífico el nivel hidrostático es muy bajo. En la provincia cordillerana es muy corriente el caso de que a pocos metros de la superficie, y aún a la simple vista, se encuentre las especies primarias; pero en las antiguas planicies de erosión glaciar (Cerro de Pasco, Cachi-Cachi, etc.) la zona de oxidación se extiende algunas decenas de metros de profundidad. El enriquecimiento de las especies cupríferas en ninguno de los dos casos ha sido notable.

Condiciones generales de la minería

El elevado tenor en plata y la circunstancia de encontrarse generalmente en zona cubierta por escasos detritus, ha influido en la explotación de los yacimientos cordilleranos, determinando preferencia sobre los costaneros, que con excepción de Cerro Verde, Ferrobamba y Tintaya, no han sido objeto ni siquiera de una seria exploración. La bondad de los depósitos chilenos de Chuquicamata y Potrerillos de la misma provincia metalogénica, como sus condiciones más favorables de ubicación, determinaron su laboreo preferencial sobre los nuestros.

En el Perú la mano de obra es abundante y barata. Según la Estadística oficial de la Dirección de Minas y Petróleo, el jornal medio pagado en 1931 por jornada de 8 horas fué de 0.55 de dólar.

La madera empleada en el ademe es mayormente el pino oregón importado de los Estados Unidos; pero también se consumió alguna cantidad de eucaliptus nacional. El costo medio del pie cuadrado del primero puesto en las boca-minas fué de $0.07, y del segundo $0.03. Faltan pocos kilómetros para que mediante una ferrovía se pueda explotar las grandes reservas madereras de nuestra Montaña.

Se usó principalmente dinamita "Dupont" de 34, 42 y 62 por ciento a un precio medio, en el mismo año 1931, de $24.17 el cajón.

La energía hidráulica, que es muy abundante y de fácil aprovechamiento, está gravada con un impuesto de $0.18 al año por cada horsepower que se aproveche, impuesto que siendo progresivo llega hasta el máximum de $0.83 cuando la concesión pasa de 8,000 horsepower. Las concesiones de menos de 51 horsepower están liberadas.

El régimen tributario minero del Perú, comprende una contribución territorial minera de $8.33 al año por cada 2 hectáreas de extensión superficial[1] (1931) y un impuesto de importación que consiste en el pago de $1.25 por "short ton" de cobre en barras, peso bruto, cuando la cotización es de $0.13 por libra más el 10 por ciento del mayor precio sobre esa cotización. La plata y el oro contenidos en las barras pagan también un pequeño impuesto.

[1] Unidad de medida para las minas metálicas llamada "pertenencia" en nuestro Código de minería.

Los combustibles empleados en la metalurgía del cobre, son petróleo nacional, antracitas y coke fabricado en el país.

Principales regiones productoras

Quiruvilca

Descripción general.—La región de Quiruvilca está 130 kilómetros al este del puerto de Salaverry, al cual está unida por una carretera y también por una vía mixta de ferrocarril, cable-carril y carretera. El cable-carril se usa solamente para el trasporte de materiales y minerales. El campamento está a una altura de 4,000 metros.

La empresa estadounidense Northern Perú Mining & Smelting Co., subsidiaria de la American Smelting & Refining Co., es propietaria de casi la totalidad de las concesiones mineras y la única que ha laboreado sin interrupción en los últimos años hasta el mes de setiembre de 1931, en que paralizó por la crisis del cobre.

Los minerales de Quiruvilca se trasportan por cable-carril a la inmediata fundición de Shorey, cuya capacidad de tratamiento es de 600 toneladas diarias y en la que se obtiene barras de cobre blister con alta ley de plata y algo de oro. En el tratamiento se usa antracita de Cayacuyán, que se conduce a la fundición por un cable-carril de 10 kilómetros.

La fuerza motriz de que dispone la empresa para sus operaciones mineras y metalúrgicas es hidráulica y con potencia de 3,600 horsepower.

Geología general.—En la zona no afloran sino rocas ígneas que se abrieron paso a través de sedimentarias del cretácico inferior, las que sólo se ven a 5 o 6 kilómetros de distancia en forma de cuarcitas valanginianas y calizas aptianas. Las primeras encierran los mantos de antracita de Cayacuyán. Las rocas ígneas postcretácicas se ofrecen con tipos efusivos e intrusivos. Las últimas atraviesan las primeras, cuyo espesor es considerable y su textura homogénea variando de composición entre la dacita y especies tan básicas que pueden calificarse de basaltos. Algunas veces se nota en ellas brechación, pero las texturas vesicular y fluidal no se conocen. Las intrusivas son rocas del tipo diorítico a textura porfídica.

Geología económica.—Se pueden reconocer dos sistemas de fracturas mineralizadas de dirección media noreste. El más importante tiene rumbo aproximado N. 50° E. e inclinación de 70°–80° SE. y comprende los principales canales por donde han circulado las soluciones mineralizadas. Hacia el sur del distrito se encuentra el otro sistema cuya dirección es N. 30°–40° S. y buzamiento al noroeste, cuya mineralización se distingue del otro por sus menores leyes en cobre y mayores en plata.

La falla llamada "Morococha," es una fractura este-oeste que ha desplazado la principal veta del primer sistema filoniano de la región, llamada "Elvira," por una distancia horizontal de cerca de 50 metros. Está mineralizada con tetraedrita argentífera que no tiene la indicada veta.

Se puede reconocer en la zona dos mineralizaciones distintas: una que corresponde a la provincia costanera y otra posterior a la cordillerana. En la primera predomina la pirita de fierro con algo de pirita de cobre y ganga cuarzosa; en la segunda la enargita y tetraedrita con algo de blenda. Como la enargita se observa a veces en fracturas independientes de las piritosas, se puede colegir que la segunda mineralización se produjo a raíz de un segundo fracturamiento y reapertura de las fracturas anteriormente mineralizadas con pirita.

Las vetas de la parte meridional de la región se caracterizan por su menor contenido en enargita y tetraedrita y mayor de blenda. El valor de ellas se basa en su contenido de plata; y sus "ore shoots" o "clavos" son esporádicos y discontinuos, lo que no ocurre con las otras fracturas.

Prácticamente no se observa enriquecimiento y la pirita de los rellenos se ha trasformado superficialmente en limonita sin producirlo.

La presencia del realgar y oropimente, minerales ligados al relleno argentífero cordillerano, revela condiciones de baja temperatura.

Se anota una intensa kaolinización de las cajas que dificulta el laboreo, exigiendo un fuerte ademe.

Los "ore shoots" se ofrecen únicamente en las vetas angostas. Son bastante constantes en longitud y tienden a presentarse "en échelon" con superposiciones ("overlappings").

Explotación.—Se hace la explotación por la lumbrera Elvira y por los pozos auxiliares Gildemeister y Graciela, a partir de los cuales se establecen niveles distantes 30 metros verticales. La preparación de las vetas se hace con galerías paralelas sobre el muro de ellas y a más o menos 6 metros de distancia.

Aunque en la explotación se ha ensayado el método "shrinkage and rill stoping" la práctica ha revelado ser más favorable el de "cut and fill horizontal back stopes." Los macizos tienen en promedio 42.5 metros de largo y una chimenea central. El relleno se hace con material escogido en los macizos y las labores de preparación. La perforación se hace usando máquinas de aire comprimido. En el ademe se usa pino oregón y eucaliptus de las inmediaciones. El desagüe se verifica con una bomba eléctrica y tubería a prueba de ácidos.

Producción.—En los años 1927–31 se extrajo de Quiruvilca 850,037 toneladas métricas de mineral y 334 de precipitados de cobre (del agua de las minas y con ley media de 54 por ciento) con un contenido total de 661.81 kilogramos de oro, 76,860 kilogramos de plata y 44,065,903 kilogramos de cobre.

Casapalca

Descripción general.—La región de Casapalca está situada al este del puerto del Callao, al cual está unido por 153 kilómetros de la conocida línea férrea Central del Perú. Comprende alturas entre 4,000 y 5,000 metros.

La sociedad minera Backus & Johnston del Perú, controlada por la Cerro de Pasco Copper Corporation, es la única entidad que ha laboreado en los últimos años, hasta febrero de 1931 en que paralizó por la crisis.

El mineral extraído de las minas se concentraba en el mismo lugar, en una planta de 500 toneladas diarias de capacidad, obteniéndose dos géneros de productos—un concentrado de flotación de altas leyes en plata, plomo y cobre que se enviaba a la Fundición de Oroya de la Cerro de Pasco Copper Corporation (distante 69 kilómetros por la línea del Ferrocarril Central del Perú) para obtenerse plomo y cobre argentíferos, y por otro lado un concentrado de flotación con alta ley de zinc que se exportaba directamente.

Geología general.—En la región aflora el Cretácico, representado mayormente por la formación de Puca ("red beds") que algunos la consideran terciaria sin fundamento alguno, cubierta por una potente formación de rocas extrusivas e intrusivas que se ha convenido en llamar formaciones del "Rimac" y "Río Blanco" (9).

El relieve de la región es muy pronunciado y de carácter fluvio-glaciar, con pequeñas morrenas cuaternarias en sus partes altas.

Geología económica.—Los yacimientos consisten en una serie de vetas rellenas con escasa mineralización del tipo costanero y abundante del cordillerano. En la primera se reconoce la presencia de la pirita, chalcopirita y ganga cuarzosa. Con la segunda se han depositado galena, blenda, tetraedrita, chalcopirita, pirita y ganga de cuarzo, rodocrosita y calcita; en las zonas marginales se encuentra bournonita, realgar y estibina.

El principal sistema de filones, Carlos Francisco-Aguas Calientes, tiene una dirección aproximada N. 40° E. e inclinación muy próxima a la vertical. Su corrida pasa a veces de 2 kilómetros y tiene varias ramificaciones de valor (veta Bella Unión). La constancia de su mineralización se revela hasta profundidades de más de 1,200 metros bajo los afloramientos. En su corrida las vetas atraviesan rocas ígneas y sedimentarias variando su potencia según los caracteres elásticos de éstas: en las ígneas y brechas porfiríticas, las fracturas están bien formadas; mientras que se angostan y se ramifican, en los conglomerados y pizarras. En profundidad tiene mayor potencia y pocas ramificaciones. Las cajas se encuentran silicificadas y piritizadas hasta distancias de algunas decenas de métros. Hay "ore shoots" bastantes extensos en longitud y profundidad; particularmente ricos en los cruces o empalmes de fracturas.

Se puede distinguir una marcada distribución zonal: con especies de temperaturas moderadas, de chalcopirita y tetraedrita cuprífera, en el centro, y realgar, estibina, pirargirita y especies volátiles en las zonas marginales.

Cuando las fracturas han atravesado algunas brechas volcánicas, se ha formado "stockworks" e impregnaciones valiosas (mina Caprichosa).

El sistema filoniano ha sido fallado con posterioridad, pero las fallas no tienen mineralización.

Explotación.—Como las vetas tienen potencias mineralizadas que rara vez pasan de 2 metros, se ha seguido el sistema de "shrinkage stoping." La extracción se hace por socavones de más de 1 kilómetro de longitud que parten del fondo de la quebrada del Rimac y que llegando a las vetas se abren en galerías y chimeneas que dividen el relleno en macizos de 30 por 40 metros en los cuales se verifica la explotación usando perforadoras de aire comprimido.

La energía usada para la explotación de las minas y el movimiento de la concentradora, se abastece aprovechando las caídas del mismo río Rimac, del cual se obtiene poco más de 3,000 horsepower, y de la hidroeléctrica de Pachachaca cuando falta aquélla.

Producción.—En el quinquenio 1927–31 se extrajeron 688,096 toneladas métricas, con un contenido de 485,560 kilogramos de plata, 8,653,222 kilogramos de cobre, 30,401,800 kilogramos de plomo y 42,923,006 kilogramos de zinc.

Morococha

Descripción general.—Morococha está a 185 kilómetros al este del Callao por el Ferrocarril Central del Perú. La altura de los campamentos varía entre 4,350 y 4,900 metros.

La principal empresa que ha laboreado los últimos años, es la Cerro de Pasco Copper Corporation, la que continúa manteniendo sus minas en actividad.

En 1932 se extrajeron 350,000 "short tons" con ley media de 4.4 onzas de plata por tonelada y 5.01 por ciento de cobre, que se enviaron a la concentradora Amistad, ubicada en la misma zona, la que trató 329,609 "short tons," obteniendo como producto de flotación 69,752 "short tons" con ley de 17.33 onzas de plata por tonelada y 21.66 por ciento de cobre, que fué remitido a la fundición de Oroya, situada a 35 kilómetros de ferrocarril.

Geología general.—En la región afloran rocas sedimentarias liásicas y cretácicas representadas por areniscas y calizas atravesadas por intrusivas como monzonita cuarcífera, pórfido granodiorítico y basaltos. Las sedimentarias están profundamente metamorfizadas en la parte central de la región (cerro San Francisco y San Marcelo). El relieve actual es netamente glaciar, y la sucesión de lagunas que caracterizan la región, muestran perfectamente la acción reciente de las nieves. Las morrenas no son muy potentes, y las lagunas se han formado por retroceso de los glaciares y represamientos de los deshielos por las pequeñas morrenas frontales.

Geología económica.—Los yacimientos principales de la región son de carácter filoniano con sustituciones e impregnaciones, todos los que corresponden al tipo de mineralización cordillerana, representada por enargita, tetraedrita, pirita, chalcopirita, blenda y galena con ganga de cuarzo predominante. En el centro de la región, ocupado en parte por un macizo de monzonita, las vetas están mineralizadas mayormente por enargita; pero las que cruzan los calcáreos colindantes, tienen gran proporción de chalcopirita. Las de las zonas marginales (Alpamina, Volcán, Pucará, Vicharayo) tienen galena y blendas con sulfuros complejos de plata que le dan ley muy elevada en este metal. Se puede pues notar en la región una marcada distribución zonal cuyo centro, ocupado por los cerros San Francisco y Santa Clara, contienen especies de temperatura moderada, mientras que en las márgenes se encuentra especies de baja temperatura.

Las sustituciones en las calizas han formado depósitos interestratificados de gran importancia (Churruca, Ombla, Alejandría, etc.).

La corrida de las vetas pasa rara vez de 1 kilómetro, pero su mineralización es muy constante en profundidad, en donde se ha podido constatar hasta más de 800 metros bajo los afloramientos.

Explotación.—Los yacimientos filonianos de poca potencia se explotan por el método del "shrinkage stoping" y cuando pasan de 2 metros se emplea "cut and fill" y "square-sets."

La extracción se hace en la actualidad por la lumbrera Central, que tiene cerca de 400 metros de profundidad, a la cual convergen las diferentes galerías de los diversos niveles de las minas en explotación. Estos niveles están generalmente establecidos cada 30 metros verticales.

Como es muy grande la cantidad de agua que tiene que extraerse de las labores, desde hace 4 años se ha iniciado un túnel de desagüe del punto llamado "Mahr" (a una altura de 3,997 metros), que en la actualidad tiene más de 6,500 metros de longitud y que deberá terminar a los 9,500 metros en la lumbrera Central.

La energía empleada en el movimiento de la concentradora y laboreo de las minas, o sean 950 y 4,684 horsepower respectivamente, se recibe de las hidroeléctricas de Pachachaca y Oroya.

Producción.—En el quinquenio 1927–31 se extrajo de la región 1,800,964 toneladas métricas, con 339,501 kilogramos de plata y 111,935,225 kilogramos de cobre.

Cerro de Pasco

Descripción general.—La famosa región de Cerro de Pasco, situada al noreste del Callao, está unida a ese puerto por 222 kilómetros del Ferrocarril Central del Perú, hasta la población de Oroya, y 132 kilómetros adicionales de un ramal de propiedad de la Cerro de Pasco Copper Corporation. Comprende alturas que oscilan alrededor de 4,350 metros.

La única empresa que trabaja es la Cerro de Pasco Copper Corporation. El mineral que extrae se conduce a la planta de flotación situada en las inmediaciones, llamada de "Quiulacocha," y el resto se traslada en crudo a la fundición central de Oroya.

Los 4,000 horsepower de energía empleada en los diversos usos de la explotación provienen de la central hidroeléctrica de Oroya.

En 1932 se extrajo de la región 298,978 "short tons" de mineral con ley media de 0.05 onza de oro y 13.25 onzas de plata por ton y 4.86 por ciento de cobre, que se remitieron en crudo a Oroya, y 6,132 "short tons" de ley de 0.09 de oro, 3.75 de plata y 4.59 de cobre que se concentraron en Quiulacocha para obtenerse 2,539.43 "short tons" de 0.133 de oro, 8.79 de plata y 15.43 de cobre que se remitieron a Oroya. La planta de Quiulacocha sólo funcionó en el mes de enero.

Geología general.—En la región afloran esquistos precámbricos y silúricos con calizas, areniscas y conglomerados mesozoicos atravesados por rocas intrusivas y extrusivas con tobas y piroclásticas de tipo monzonítico. Hay encima de todo esto, morrenas frontales no muy potentes; y el relieve general de la región es de carácter netamente glaciar, con formas aborregadas y un remodelado reciente de carácter fluvial.

Geología económica.—Hay yacimientos filonianos de potencia variable desde pocos centímetros hasta 10 metros y marcada verticalidad y también grandes masas de impregnación y sustitución de las rocas sedimentarias e ígneas que forman cuerpos potentes y de extensión predominantemente horizontal.

La mineralización es únicamente del tipo cordillerano o cuproargentífero con minerales de media y baja temperatura tales como la pirita, enargita, famatinita, luzonita, chalcopirita, tetraedrita, bornita, calcocita, bismutina, blenda, bournonita y galena con ganga predominante de cuarzo y calcita. La sustitución de las calizas e impregnación de las areniscas y tobas han formado enormes depósitos, algunos de los cuales son excepcionalmente ricos en cobre.

Las vetas se encuentran sobre todo al oeste y sur de la región, atravesando indistintamente las rocas sedimentarias e ígneas.

En la zona de los depósitos, la oxidación que encontró un terreno permeable se extendió hasta más de 100 metros de profundidad, mientras que solamente llega a algunas decenas de metros en el caso de los filones. En algunos casos se han observado con motivo del enriquecimiento de los depósitos, grandes bolsonadas de plata nativa, argirosa y haloides que dieron fama a la región en tiempos pasados.

Las reservas minerales en la actualidad son como sigue:

	Toneladas métricas	Cobre (por ciento)	Plata (onzas por tonelada)	Oro (onza por tonelada)	Plomo (por ciento)	Zinc (por ciento)
De cobre.............	3,000,000	4.00	5.0	0.06	....	....
De zinc y plomo........	4,000,000	.20	4.6	....	7.2	15.3
Oxidados (pacos).......	12,000,000	.05	11.0	.01	2.0	....

Explotación.—La extracción se hace por varias lumbreras, algunas de las cuales llegan hasta 500 metros de profundidad (Excelsior y Lourdes).

En los depósitos se emplean los métodos de "cut and fill" y "square-sets" con relleno; así como "glory holes," en el caso de estar próximos a la superficie. En las vetas que no tienen gran potencia, se emplea el "shrinkage and rill stoping."

El desagüe se hace con bombas eléctricas hasta el nivel del socavón Rumiallana; y en el taladreado se usa perforadoras de aire comprimido.

La energía que se emplea para todo el laboreo e instalaciones superficiales con potencia de cerca de 4,000 horsepower, se recibe de la central hidroeléctrica de Oroya.

Producción.—En el lustro 1927–31 se extrajo de toda la región del Cerro de Pasco 2,170,532 toneladas métricas con 3,350.38 kilogramos de oro, 686,600 kilogramos de plata y 89,847,361 kilogramos de cobre.

Otras regiones

La producción de las regiones de Cerro de Pasco y Morococha en 1932 representó alrededor del 90 por ciento de la total del país; las otras zonas productoras han tenido pues reducida significación.

Con el fin de hacer más completa nuestra información debemos hacer una ligera referencia a la región de Quequeña del departamento de Arequipa, en donde la Compañía Minera Rescate, controlada por la firma Mauricio Hochschild, laboreó principalmente las minas Hermenegilda y Ampliación 6ª, situadas a 26 kilómetros al sudeste de la ciudad de Arequipa. Los yacimientos trabajados son de carácter filoniano y la mineralización de tipo costanero. En el quinquenio 1927–31 se extrajo 64,436 toneladas métricas con 43.48 kilogramos de oro, 2,201 kilogramos de plata y 1,736,089 kilogramosde cobre, mineral que se condujo por un cable-carril de 8 kilómetros a la concentradora de Yarabamba, de 80 toneladas diarias de capacidad, en donde se obtuvieron concentrados de alta ley que se remitieron en camiones hasta Arequipa (18 kilómetros) y de allí al puerto de Mollendo por 172 kilómetros de ferrocarril. En 1932 se exportó 1,334,317 kilogramos de concentrados con 10.54 kilogramos de oro, 397 kilogramos de plata y 372,614 kilogramos de cobre.

También en el mismo año las cifras de exportación de cobre están integradas por pequeñas cantidades provenientes del beneficio de minerales principalmente auríferos y argentíferos que se extrajeron de las regiones de Colquipallana, en el departamento de Lima; Collaracra, en el de Ancash; Cailloma, en el de Arequipa; y Santa Lucía, en el de Puno.

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Copper in the Cerro de Pasco and Morococha districts, Department of Junin, Peru[1]

By D. H. McLaughlin,[2] L. C. Graton,[3] and others

General introduction

Authorship

The general setting of the important copper-producing districts of Cerro de Pasco and Morococha, which lie about 70 miles apart in the high Sierra of central Peru, may well be presented collectively and followed by more special description of each district.

This statement embodies information gained chiefly by the geological department of the Cerro de Pasco Copper Corporation, the principal operator in each of the districts. Foremost among direct contributors is Mr. W. F. Walker, chief geologist since 1925, who has supervised the assembly of many of the data incorporated herein. Messrs. H. C. Burrell and Samuel I. Bowditch, recent members of the department at Morococha and Cerro de Pasco, respectively, have participated actively in the preparation of this account, as have O. C. Schmedeman

[1] Published with permission of the Cerro de Pasco Copper Corporation.

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and T. G. Moore, now located respectively at Cerro de Pasco and Morococha. Among the many former members of the staff whose work has contributed directly to our present understanding of the geology, specific mention must be made of Messrs. C. M. Farnham, M. G. Edwards, the late W. L. Uglow, Rodgers Peale, J. O. Hosted (now assistant superintendent at Cerro), J. A. Noble, the late R. D. Harvey, P. W. Chase, N. R. White, and particularly John M. Boutwell, consulting geologist of the corporation during 1918–19, who laid the foundation for detailed geologic work in these areas.

Effective cooperation and support have been given throughout by the mine-operating department and by Mr. Harold Kingsmill, general manager of the corporation.

This paper makes no claim to finality, for steady progress by the geologists of the corporation continues to be made, and advancement in our knowledge of the ore deposits of the region can be expected as long as the mines are active.

Geography

Morococha, though within 75 miles of the Pacific Ocean, is at an altitude of 14,800 feet on the eastern flank of the main range of the Andes, in a glaciated basin only a couple of thousand feet lower than the ice-clad peaks along the Continental Divide. Cerro de Pasco lies in an area of more subdued topography at an altitude of 14,200 feet, in a belt of high country known as the Nudo de Pasco, which crosses the Andean plateau of central Peru about 90 miles north of the latitude of Lima. The port of entry is Callao, from which the mines are reached by the Ferrocarril Central del Perú. A short branch line extends from Ticlio over the Anticona pass, at 15,865 feet, into the Morococha district, and both the main line of the railway and the branch descend to the smelting center at La Oroya, 138 miles from the coast. From La Oroya the Cerro de Pasco Railway extends 82 miles to the north across the plains of Junin and adjacent uplands to the older district. An automobile road, 180 miles in length, has recently been completed to Cerro de Pasco through the Paso de la Viuda.

Climate

Cool weather prevails throughout the year in the plateau region, but the temperature rarely falls more than a few degrees below freezing. Precipitation, often in the form of snow or hail, is heaviest in the months of the southern summer (November to April). The dry season during the winter months (May to October) is by far the pleasanter time of the year, though the average temperature is slightly lower. Storms, though not infrequent, are of short duration; clear skies and brilliant sunny days are the rule. Close to the high peaks, as at Morococha, the climate is somewhat more severe, but even there extremely low temperatures are unknown.

Summary of regional geology (7, 11, 12, 13)

In the plateau country of central Peru the oldest exposed rocks are slightly metamorphosed shales and sandstones (the Excelsior series). Fossils are lacking, and uncertainty still exists whether these beds are to be correlated with somewhat similar formations of Silurian age or with rocks considered to be late pre-

Cambrian. Folding and erosion intervened before Carboniferous sediments were laid down. The late Paleozoic is represented in the high country only by conglomerate and sandstone (the Mitu formation) and possibly by a thick accumulation of pyroclastic material and flows known as the "Catalina volcanics," found between the Excelsior formation and Jurassic limestones in the region near Morococha.

The most conspicuous rocks of the plateau are Mesozoic limestones, which occur both above and below coal-bearing sandstones and shales of the Lower Cretaceous. The major formations are the Pucara, Paria, or Potosi limestone (Triassic-Jurassic), the Goyllarisquisga or Toribio sandstone (Wealden), and the Machay limestone (Aptian and other Lower Cretaceous epochs). These formations are distinctive lithologic and structural units (11). More detailed paleontologic study, however, is needed for their exact definition and subdivision.

Widespread deposition of terrestrial sediments (now limestone conglomerates, red shales, and sandstones with thin limestone members), following a period of folding and erosion, marked the end of the Cretaceous and beginning of the Tertiary. These beds, to which the regional name "Rimac formation" may be applied (12), were themselves folded and eroded before being buried by a great thickness of volcanic material (Rio Blanco formation), probably in early Tertiary time (13).

A final intensive folding of the region, in which the volcanic beds were deformed, preceded a period of intrusive activity marked by the development of batholiths on the lower western slopes and of numerous stocks and minor bodies in the high country. Granodiorite with related porphyritic rocks is the prevailing type. The mineral deposits of the region are most commonly associated with stocks having relatively small areas of outcrop. Except for a few rather minor sills, mostly basaltic, in the Mesozoic formations, the intrusive rocks of the region are confined to this post-Cretaceous period.

Four major periods of folding and related faulting produced a succession of irregular broken anticlines and synclines with a prevailing N. 10°–30° W. trend throughout the region. In the plateau country the older formations are exposed over wider areas along somewhat broader arches than in the main range and on the upper western slopes, where red beds and later volcanic rocks prevail in more tightly compressed structures. The most conspicuous fractures are reverse faults parallel to the trend of the folds, with complicating oblique breaks associated with irregularities in plunge. Most of the reverse faults appear to have dips steeper than 40°, but evidence for at least one extensive flat overthrust has been observed by J. A. Noble.

Fracturing subsequent to the Tertiary intrusions presented new patterns in part. Transverse cracks, generally with relatively minor displacement, break the stocks and adjacent rocks in the mineral districts, and many of the cracks are followed by veins. Renewal of movement on earlier longitudinal breaks and some minor faulting followed the principal period of mineralization, but regional deformation was probably limited to large block movements related to the uplift of the present range, which has left little record in the ore deposits.

Erosion to a surface of low relief followed the deformation in early Tertiary time. The present range is the result of broad uplift subsequent to the development of this surface. The uplift occurred probably in at least three stages, accompanied by some warping and block faulting. The relatively smooth topography of the old surface is preserved in much of the plateau area. The hills about Cerro de Pasco rise only slightly above it, and the great canyons of the later stages of erosion, though nearby, have not yet reached the mineral district. The lofty western range may mark a line of older mountains along the belt of latest folding and maximum igneous activity, but the abrupt escarpments of certain ridges suggest faces of blocks resulting from the more recent uplifts.

Most areas above 14,000 feet are glaciated. In the region of milder topography around Cerro de Pasco glacial erosion was not vigorous enough to remove supergene ores, but in districts situated near the crest of the range, such as Morococha, nearly all traces of earlier alteration have been obliterated.

The Cerro de Pasco district

By Donald H. McLaughlin, Samuel I. Bowditch, and others

Introduction

History and production (1, 2, 3, 10)

In 1630 silver ore was reported to have been obtained from a locality known as "Santa Rosa," in the Cerro de Pasco district. With the energy characteristic of the times, numerous bodies of rich oxidized ores were soon discovered in the extensive area of iron-stained croppings, and active production of silver started, which was maintained with few interruptions for nearly 200 years. During the colonial period water limited mining to relatively shallow workings, but early in the 19th century pumps installed by Trevithick, who was in the district from 1816 to 1819 (3), permitted somewhat deeper operations. Later the district was drained to a depth of about 300 feet by the Quiulacocha tunnel, started in 1806 (10) and actively advanced by Rivero in 1827 and 1828.

The mining industry in Cerro de Pasco, as elsewhere in the region, suffered greatly during the first disturbed decades of the Republic and during the difficult years following the war with Chile, but the district still continued to maintain its place as the leading silver producer of the country. Copper ores, though utilized for the sulphate (magistral) needed in the patio process, did not receive serious attention until the nineties, when completion of the Ferrocarril Central to La Oroya reduced transportation costs sufficiently to make it profitable to smelt richer ores and ship matte. A number of small furnaces were built during these years and were active until 1901, when the major properties were purchased and consolidated by James B. Haggin and his associates, and operations on the modern scale started with the building of the Cerro de Pasco Railway from La Oroya (completed in 1904), the construction of the smelter at Tinyahuarco, and the opening of coal mines at Goyllarisquisga, as well as installation of the mining plant necessary for extensive exploitation of the ore bodies. Several other properties, notably the mines of E. E. Fernandini, the Docena mine, and various smaller operations, benefiting by the new transportation and metallurgical facilities provided by the large company, were worked successfully during the succeeding years and made substantial contributions to the output of the district.

The mines owned by the American group, from which the bulk of the production is maintained at present, are now a unit of the Cerro de Pasco Copper Corporation, formed in 1915 as a merger of the railway, smelter, and mines at Cerro Pasco, Morococha, and elsewhere. All ores and concentrates from the district are now treated at the Oroya smelter, completed in 1923, from which silver-bearing blister copper, lead bullion, and bismuth are shipped to the coast for export.

Metals produced in Cerro de Pasco district, 1928–32

Year	Copper (pounds)	Lead (pounds)	Silver (ounces)	Gold (ounces)
1928	37,510,338	25,036,000	5,028,830	17,262
1929	47,835,610	26,018,000	6,549,550	24,713
1930	42,271,210	15,984,000	3,962,140	25,743
1931	49,726,490	14,412,000	3,502,017	32,635
1932	32,676,548	11,074,000	4,390,850	17,001
	210,020,196	92,524,000	23,433,387	117,354

Topography

The town and the nearby mineral deposits lie in a broad glaciated basin surrounded by hills 500 to 1,000 feet higher. The district is on the divide between two major streams whose waters follow widely separated courses to the Amazon. To the south the country drains through broad grassy valleys into Lake Junin and the Mantaro River, but to the north it breaks abruptly into deep canyons which descend with steep gradient to the Huallaga River. Toward the east the plateau country is interrupted by canyons before the lofty peaks of the Cordillera Oriental are reached, but toward the west the high surface continues almost unbroken to the base of the main range, which rises abruptly as a sharp wall with numerous peaks over 17,000 feet.

General geology

Only an incomplete geologic section exists at Cerro de Pasco, but by correlation with other areas where relations are more clearly shown, the sequence and significance of the local rocks are believed to be fairly well established. The formations of the district are listed below. (See fig. 60.)

Geologic column at Cerro de Pasco

Quaternary	Glacial deposits.
Early Tertiary	Cerro quartz monzonite porphyry and related intrusives.
Tertiary (?)	Rumiallana agglomerate.
	Lourdes fragmental.
	Calera limestone.
	Shuco limestone and conglomerate.
Jurassic-Triassic	Paria limestone.
Carboniferous (?)	Mitu conglomerate and sandstone.
Early Paleozoic or late pre-Cambrian	Excelsior series.

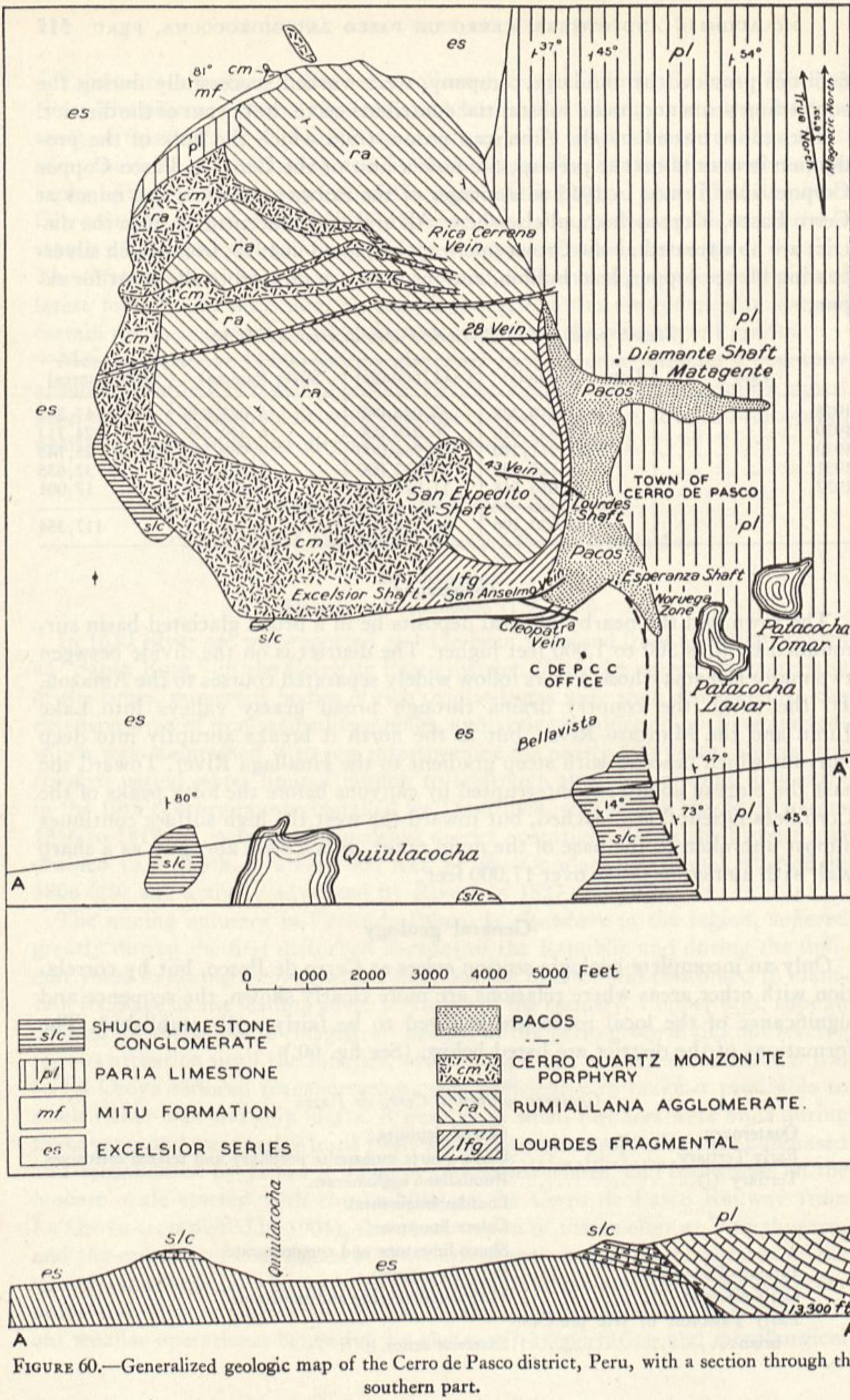

FIGURE 60.—Generalized geologic map of the Cerro de Pasco district, Peru, with a section through the southern part.

The prevailing member of the Excelsior series near Cerro de Pasco is a shale, usually intricately deformed and partly recrystallized to a rock approaching a phyllite in texture. Quartzite layers are interbedded with it. The Mitu formation outcrops immediately north of the mineralized area, but it is not positively known in the mines. The Paria limestone forms the surface in the eastern half of the district; its lower members are considered to be of Triassic age; the overlying beds contain a fauna that has been correlated with the Lias, but no sharp boundary has been drawn. The Goyllarisquisga sandstone and the overlying Machay limestone are missing near Cerro de Pasco but occur within about 2 miles to the northwest.

Folding at the close of the Cretaceous period, possibly accompanied by some faulting, produced a broad arch with northerly trend, along which the underlying Excelsior beds were exposed by erosion before the limestone conglomerate of the Shuco formation was deposited. This rock is composed of coarse irregular boulders of Mesozoic limestones set in a sandy limestone cement. To the west and south of the district it is overlain by reddish shales and by the conspicuous white Calera limestone.

A renewal of compression resulted in an eastward-dipping fracture known as the "Longitudinal fault," along which Paria limestone on the east side of the anticline was pushed over the younger Shuco conglomerate. Sharp folds in the Calera limestone and in overlying red beds a few miles to the west were probably formed during the same period of disturbance.

The igneous rocks, except a few minor flows and sills in the Excelsior series, are confined to a roughly circular area about a mile in diameter in the northwestern part of the district, which appears to be a volcanic vent somewhat modified by faulting on the south side and possibly on the east side. A white fragmental rock (the Lourdes), which outcrops in a crescent-shaped area around the southern and eastern margins, is the oldest unit. Its exact nature is still unsettled. In most exposures it resembles a quartz monzonite porphyry with numerous small gray quartzite inclusions. On weathered surfaces the igneous matrix itself is seen to be coarsely fragmental. Locally it grades upward into a gray rock in which bedding finally becomes distinct.

This overlying formation, the Rumiallana agglomerate, occupies the major part of the volcanic area and may have originally extended beyond its margins. It is a roughly sorted mixture of gray volcanic detrital material with scattered boulders of limestone, porphyry, Lourdes fragmental, and rocks of the Excelsior series. Sharp contacts with the Lourdes fragmental occur, as well as the gradational change mentioned above.

Both these formations are intruded by the light-gray Cerro quartz monzonite porphyry, which outcrops in an irregular area on the west side of the district, in contact with Excelsior rocks on the west and south and with Rumiallana agglomerate elsewhere. Later dikes of slightly different texture and composition cut the Cerro porphyry and extend from it with easterly strike into the agglomerate and in one place into limestone. A small area of white porphyry lying north of the larger body greatly resembles the Lourdes without the fragmental texture.

Ore deposits

General types

Differences in primary nature and in alteration by supergene processes divide the deposits of the Cerro de Pasco district into the following groups (see fig. 61):

1. Longitudinal pyrite body and associated hypogene ore shoots:
   - Copper ores in irregular bodies and in transverse veins in the pyrite.
   - Lead-zinc-silver ores.
   - Pyritic silver ores.
2. Transverse veins in Excelsior series and in volcanic rocks, with copper-silver ore shoots.
3. Mantos in Paria limestone:
   - Lead-zinc-silver ores (Matagente ore bodies).
   - Copper ores with subordinate silver (Noruega ore bodies).
4. Supergene sulphide ores.
5. Oxidized silver ores (pacos), locally with subordinate lead.

Mineralogy

Arsenical and antimonial sulphosalts of copper and silver, which are characteristic of the mineralization throughout the Peruvian Andes, are conspicuous in the Cerro de Pasco district. Enargite is the dominant hypogene copper mineral. It occurs abundantly both as bladed crystals in clusters and irregular aggregates and as the variety luzonite, easily distinguished by its pinkish tinge and dense texture, though almost identical in chemical composition and other properties. All enargite that has been tested has been found to contain antimony as well as arsenic, and much of it might properly be termed "enargite-famatinite," though the antimony is usually subordinate. Tetrahedrite-tennantite is closely associated with much of the enargite and is the principal mineral in certain veins. It likewise contains both arsenic and antimony. Not enough samples have been analyzed to establish whether antimony or arsenic is dominant; there appears to be some variation in the ratio of these elements between different ore bodies. The tetrahedrite-tennantite is everywhere silver-bearing and is the principal source of silver in the copper veins. Chalcopyrite is only sparsely developed and is rarely seen except under the microscope.

Chalcocite with subordinate covellite is abundant in many shoots of supergene ore. The richest copper ores are incoherent masses of sooty chalcocite and residual pyrite; in more massive ores the chalcocite forms veinlets in hypogene sulphides (chiefly sphalerite) or rims their grains in clearly supergene relations. Oxidized copper minerals, including malachite, azurite, cuprite, and native copper, are locally abundant but form only relatively small ore bodies.

Ruby silver, argentite, and stephanite are found in the richer silver ores with low copper. Native silver is present in the oxidized zone and to some extent in the zone of secondary sulphides, but it is rarely seen by the unaided eye, and probably only a small part of the silver content of the ores can be attributed to it.

Galena and sphalerite are abundant ore minerals in large masses that usually contain some silver but very little copper. Cerusite is sufficiently abundant to be of commercial value in parts of the oxidized zone. Some smithsonite is found on the limestone side of the district, but for the most part oxidized zinc minerals (except efflorescences of goslarite on drift walls) are difficult to detect.

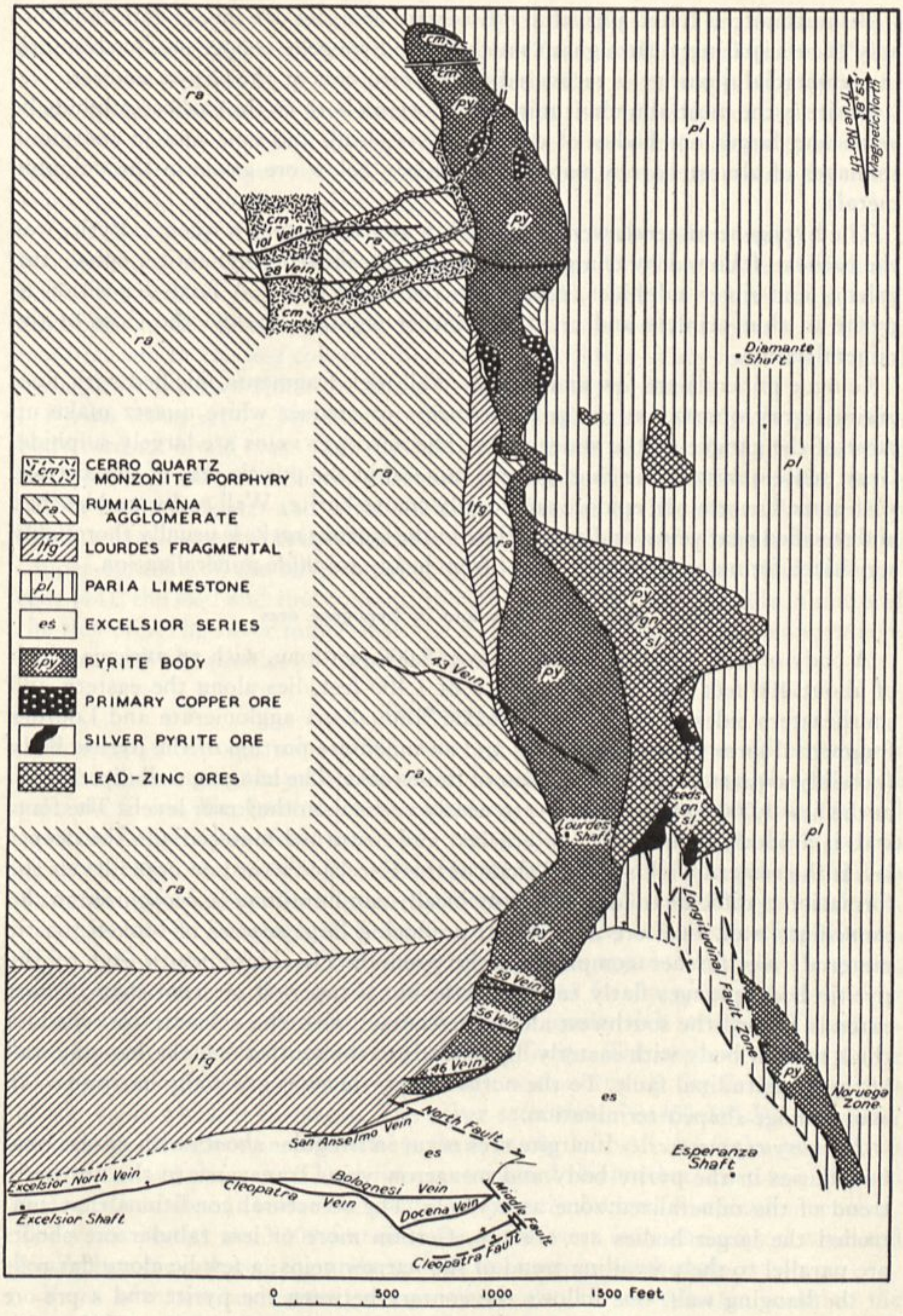

FIGURE 61.—Generalized geologic plan of the ore bodies of the Cerro de Pasco district at the 600-foot level (elevation approximately 13,620 feet).

Bismuthinite is found plentifully in certain enargite ore shoots and undoubtedly occurs sparingly throughout much of the hypogene copper ore, for bismuth in commercial quantity is recovered from Cerro ores at the Oroya smelter.

Pyrite is the most abundant mineral. It occurs both as the earliest sulphide in veins and larger ore bodies of copper, silver, lead, and zinc and in enormous tonnages of almost barren material hopelessly below ore grade in the valuable metals.

The hypogene minerals were deposited in an overlapping sequence. Pyrite was the earliest, followed by enargite (luzonite), tetrahedrite-tennantite, sphalerite, galena, and silver sulphides, roughly in the order listed. A final deposition of pyrite in thin veinlets and crusts on earlier crystals marked the close of the mineralization.

Gangue minerals are few and simple. Wall-rock fragments silicified with fine-grained gray quartz and irregular stringers of coarser white quartz make up most of the gangue of the wider veins. The narrower veins are largely sulphide. Gray dense quartz is the chief gangue mineral in the pyritic ores of the district, with some fine-grained epidote and locally coarse barite. Wall rocks are bleached and silicified near veins, and plagioclase in the igneous rocks is usually thoroughly sericitized for many hundreds of feet from heavy sulphide mineralization.

The pyrite body and its hypogene ores

A body of heavy pyritic material, over 5,000 feet long, with an average width of about 400 feet and a known depth of 1,400 feet, lies along the eastern and southeastern sides of the volcanic rocks. Rumiallana agglomerate and Lourdes fragmental form the hanging wall, and an indefinite portion of the pyritic body (possibly a quarter) is a replacement of these rocks. The hanging wall dips 70° W. in the first 1,000 feet but steepens to nearly vertical on the lower levels. The foot-wall is a poorly defined zone of crushed and disturbed material. On the deeper levels the eastern wall is altered shale of the Excelsior series; on upper levels the formation is difficult to identify. Only locally can limestone be recognized in the immediate wall. Post-ore movement, producing large masses of broken pyritic material, has further complicated the ground. The blunt south end of the pyritic body plunges flatly to the north, but a tapering crescent-shaped mass extends toward the southwest along the contact with the volcanic rocks, and a thick tabular body with easterly dip extends to the south along the hanging wall of the Longitudinal fault. To the north the pyrite body gradually narrows to an acute wedge-shaped termination.

Primary copper ores.—Enargite ores occur in irregular shoots with gradational boundaries in the pyrite body and in narrow veins transverse to the northerly trend of the mineralized zone as a whole. The structural conditions that controlled the larger bodies are obscure. Certain more or less tabular ore shoots are parallel to the prevailing trend of the narrow veins; a few lie along flat rolls in the hanging wall; one follows the contact between the pyrite and a pre-ore quartz monzonite dike. They vary greatly in size and vertical extent. Only a few persist for more than 300 feet vertically. Much bismuth is recovered from these ore bodies, but in only one is bismuthinite conspicuous.

Most of the copper veins in the pyritic body are narrow stringers of enargite and related sulphides with little or no gangue. The prevailing strike is N. 70°–90° W., and the dips are usually steep to the north. The veins stop abruptly at the shale contact on the east and rarely persist into the volcanic rocks on the west except as narrow stringers, though they may be strong and rich up to the contact. The silver-copper ratio decreases with depth on certain veins. In many veins the gold content is noteworthy.

Lead-zinc ores.—Portions of the pyrite body contain galena and sphalerite in sufficient quantity to be classed as lead-zinc ores. The boundaries of such ore bodies are gradational, and their shape is irregular. They are most abundantly developed in the eastern portion of the pyritic mass, both in massive sulphide material and in the less coherent border ground. Silver is unevenly distributed throughout the lead-zinc ores, but a little is usually present.

Pyritic silver ores.—The largest silver ore shoot associated with the pyrite body forms a broad mass with northerly rake at the south end of the zone. For the most part the ore is heavy pulverulent ground, with abundant pyrite, some galena and sphalerite, and silver minerals. Massive pyritic material is usually low in silver, except locally adjacent to richer bodies in the border zone. The copper content of the silver-bearing pyrite ores is usually less than 0.5 per-cent (14); the lead and zinc content, though locally high, is negligible in much of the rich ore. The silver minerals in the pyritic ores are discussed below, in connection with the problem of supergene enrichment.

Transverse veins

A group of strong veins along curving branching fractures with westerly course occurs in the altered shales of the Excelsior series on the south side of the volcanic rocks. The fractures are transverse to the contorted bedding, as well as to the Longitudinal fault zone and to the major axis of the pyrite body, which lie to the east and north. The most northerly member of the group, the San Anselmo vein, follows the contact between shale and Lourdes fragmental. Toward the east its hanging wall is massive pyrite in a curved, wedge-shaped mass, which gradually thickens as the main pyritic body is approached. The Cleopatra, the strongest vein in the district, averages over 15 feet in width but toward its extremities becomes reduced to narrow though locally rich stringers. The structure is complicated by two sets of post-ore faults. The earlier (known as the "Cleopatra fault") is a hinged reverse fault with northerly dip flatter than that of the veins which it displaces. The other set strikes N. 45°–50° W., obliquely across the veins, and in plan offsets them to the left. All the faults apparently die out toward the west. The veins curve toward the north as they are followed eastward and die out before the pyritic body or the Longitudinal fault is reached. The veins persist for 3,100 feet or more to the west from the central zone and finally become reduced to unmineralized fractures in black shale.

Veins with similar westerly course occur also in the volcanic rocks to the north. Most of the ore shoots of minable width thus far developed on such veins are found within 1,000 feet of the pyrite body. A few local ore shoots attain a width of 10 to 15 feet. Ore occurs in fragmental, agglomerate, and quartz monzonite. The walls are fairly well defined, though they are rarely clean breaks. A few veins appear to be westward extensions of veins in the pyrite, though such relations are exceptional. In the southern and middle ground the strongest veins strike about N. 60° W. and dip 45°–60° N. In the northern area they strike approximately east and dip 60°–80° S.

Mantos in Paria limestone

The mineralized zone extends eastward into the Paria limestone in the Matagente area, in the northern part of the district, and in the Noruega zone, in the southern part. In the Matagente area thick roughly tabular sulphide bodies were formed by replacement in limestone beds with flat easterly dip. The ore is now mostly oxidized, but the sulphide remnants indicate that it originally consisted of pyrite, galena, and sphalerite, with a good tenor in silver and only locally a little copper.

The Noruega mantos, dipping 60° E., lie in the immediate hanging wall of the Longitudinal fault. They are considered further under secondary sulphide ores.

Secondary sulphide ores

Rich chalcocite ores were the principal source of copper for many years in the Cerro de Pasco district, but the production from them has gradually diminished to a relatively small part of the total tonnage of copper ore now mined. The secondary copper ores do not form a uniform blanket over all parts of the pyrite body but are localized in large but definitely limited shoots where conditions prevailed that favored copper sulphide enrichment. An adequate amount of copper in the hypogene ore, oxidation and leaching of a substantial thickness of mineralized ground, existence of fractures or other permeable zones permitting downward percolation and permeation into the underlying sulphides by copper sulphate solutions, and the presence of sphalerite to precipitate the copper as chalcocite appear to have been necessary conditions.

The richest ore is black pulverulent material, containing abundant chalcocite and some covellite with residual pyrite. Galena and sphalerite are clearly most susceptible to enrichment; enargite is replaced less easily; and attack on pyrite is limited to thin black films, even where chalcocite is abundantly developed.

The chalcocite ore bodies usually lie immediately below the bottom of the pacos. A few feet of leached sandy pyrite was found in one place above chalcocite ore, but generally the transition from sulphide ore to pacos is sharp. In the Diamante mine secondary copper ore bodies are extensive on the 200 level, but on the 400 level they become reduced to a few irregular ore shoots that bottom a few tens of feet deeper in pyritic material, usually with abundant sphalerite and galena but below ore grade in copper. Richer ores occur at the south end of the pyrite body in the Peña Blanca ground and in the mantos of the Noruega zone, where a shoot of secondary ore between 20 and 45 feet thick was mined almost without interruption for 1,000 feet along the strike. The ore bottomed against bleached and altered limestone and shale with some pyrite and sphalerite at a maximum depth of about 500 feet. In this place the end of the primary ore apparently coincided with the bottom of the zone of supergene alteration. The ore shoot is overlain by pacos to a depth of 200 feet. A band of cerusite ore rich in silver follows the footwall of the chalcocite body for about 100 feet below the top of the sulphide body in the northern part of the zone.

The bottom of the zone of oxidation and the depth reached by enrichment are much more irregular than the present surface. Unaltered pyrite outcrops in several areas, but elsewhere oxidation is complete to depths of several hundred feet below the pre-mine ground-water surface. The distribution of oxidation was undoubtedly determined to a large extent by the nature of the ore body and the surrounding rocks. Oxidation and enrichment are believed, however, to have been carried very nearly to their present state in preglacial time, and possibly the irregularities may be attributed in part to alteration from a preglacial surface that did not conform in detail to the present topography and to a preglacial climate when arid conditions may have existed.

Silver was retained in the oxidized zone rather than leached from it, and consequently the quantity of metal available for supergene sulphide enrichment has been relatively small. Threads of native silver and thin veinlets of argentite in chalcocite, which can be detected on polished surfaces of rich specimens from various secondary copper ore bodies, are undoubtedly of supergene origin, but the actual increase in silver content due to these minerals is probably slight. In the pyritic silver ores, where very little copper occurs, the amount of enrichment is even more difficult to appraise. Silver-bearing tetrahedrite, conspicuous in a few spots, is certainly of hypogene origin, but it is practically absent in most of the ore. Ruby silver and stephanite, which can be detected in the highest-grade silver ore, are late in the mineral sequence, but definite proof of supergene origin is lacking. Native silver, argentite, and stromeyerite are so rare that only a very small part of the silver could be attributed to them. Changes with depth might be taken as suggestive of supergene origin for the principal silver-pyrite ore body, but comparable variations within the same vertical range have been exhibited by other ore shoots of undoubted hypogene character. More work is still to be done before the question can be considered closed, but on the basis of evidence now available the conclusion seems warranted that supergene silver sulphides, though locally detectable, have not been formed in sufficient abundance to create ore shoots in material originally below minable grade.

Oxidized silver ores (pacos)

The greater part of the mineralized section of Cerro de Pasco is covered by a mantle of siliceous silver-bearing material, locally called "pacos," that has resulted from the oxidation of sulphide deposits. It ranges in thickness from a few feet to several hundred feet and is developed over an area of more than 80 acres. Most of it lies over the pyrite body and associated ores, though a long tongue extends to the southeast over the Noruega zone, and another in the north end of the district extends to the east in the Matagente area. Parts of the pacos are rich enough in silver to be mined profitably at the present time for converter flux, but the greater part does not justify exploitation at present metal prices.

The pacos vary in composition (14) with the nature of the original material and of the adjacent rock. In the central and southern areas, where the environment is neutral, sulphur is cleanly leached, much of the iron is removed, and the silica content of the pacos is highest, owing to residual concentration. Lead and zinc are low, and a good recovery of silver can be made without roasting the ore. In the Noruega and Matagente zones, however, with limestone in the immediate vicinity, lead and zinc are held as carbonates in the pacos, iron is retained as limonite to a much greater degree, the percentage of silica is lower, and the silver is refractory, though the grade of much of the ore is above average.

The form in which the silver occurs is difficult to determine and merits further investigation. Native silver is present, but except in very rich portions it is not the dominant form. Halides probably exist, but in minor amounts.

Copper is leached to a remarkably complete degree from the siliceous parts of the pacos. Oxidized copper ores containing cuprite, malachite, azurite, and native copper occur in a few small bodies in the eastern ground, where the effect of the limestone was dominant.

The silica of the oxidized materials is mostly dense microcrystalline quartz. Yellow and brown limonites occupy cavities formerly held by sulphide or impregnate siliceous and kaolinic material. Sulphates and carbonates are only locally conspicuous.

Genesis

Gossans in the limestone conglomerate and veins in the volcanic rocks indicate that mineralization was subsequent to these formations. Ore bodies are as yet unknown in the main body of the quartz monzonite porphyry, but veins cut several of the younger dikes. Numerous pyrite stringers and abundant sericite in the plagioclase afford further proof that the mineralization was later than the consolidation of the intrusives.

The major fracture patterns of the region were established before metallic ores were introduced, though some final movement on the Longitudinal fault and on transverse breaks occurred later. The mineralization may thus be placed at the end of the period of igneous intrusion in early Tertiary time, subsequent to the last major deformation but prior to the subsiding final disturbances.

Zoning is far from perfect but nevertheless clearly points to the vent as the center of mineralization. The largest sulphide body is virtually on the vent margin. The veins in the volcanic rocks and in the Excelsior beds immediately adjacent are highest in hypogene copper minerals and in gold. Lead-zinc ores in the pyrite body are almost exclusively on the limestone side of the zone, and the silver-pyrite ores likewise are on the margin away from the volcanic rocks. In the intermediate ground, however, copper is also present, though most of the high-copper ores in this area can be attributed to supergene enrichment rather than to abundance of enargite. Lead-zinc-silver ores with no copper are found in the Matagente ground, most remote from the igneous center.

The association between metallic ore deposits and small stocks is so striking a characteristic of the Andean region as a whole that in this particular case the mineralization may with confidence be regarded as a late product of the igneous activity which at earlier stages produced the fragmental rocks of the vent and the porphyries that intrude them.

The Cerro intrusive is frankly porphyritic and is accompanied by fragmented vent phases, which likewise suggest that these rocks were formed under no very great thickness of cover. This suggestion appears to be in accord with the indications afforded by the related ore deposits, in which mineralogy and texture imply depth-intensity characteristics generally similar to those at Morococha, though probably somewhat feebler. The Cerro ores exhibit certain genetic affiliations to those of the silver district of Colquijirca (20), which lies a few miles to the south, but are of definitely deeper-seated character.

The Morococha district

By L. C. Graton, H. C. Burrell, and others

Introduction

Geography

Morococha, strikingly set in an eastward-trending alpine valley of rugged beauty, is surrounded by lofty, glacier-capped peaks of the Western Cordillera that rise above 17,000 feet. The district lies 8 miles east of the Continental Divide, some 70 miles east of Lima, and 17 miles west of the smelting center La Oroya. Branches of the Ferrocarril Central enter it from east and west.

The principal mines, at an altitude of about 14,900 feet, occupy an area of about 5 square miles within a somewhat larger region of feebler mineralization. The highest of the old adit workings are at nearly 16,000 feet, and the present deepest development (1,000-foot level) is at 13,900 feet. Development about 500 feet deeper and elimination of the present very heavy pumping (averaging 15,000 gallons a minute) will be accomplished by the Mahr tunnel, now well advanced from Yauli Valley, 6 miles to the southeast (16, 18, 19, 21).

History and production (5, 6, 10)

The probability that ores were mined at Morococha in pre-Spanish times, as was certainly true in other Peruvian districts, is indicated by the primitive workings and implements found by later operators. Silver production evidently proceeded during colonial times; and a small, fluctuating output of silver and lead continued until about 1850, when richer ores appeared and activity increased. In the later eighties some mines were producing ore of 50 percent lead and 60 ounces of silver to the ton. But in the nineties the silver-lead ores declined in grade, and never thereafter did they regain real importance.

Copper production started in the fifties, on a small scale, to supply copper sulphate used in the silver lixiviation plant at Tuctu, a mile below the mines. By the middle nineties rich copper ore had been discovered, though on a scale that would not now seem important. A concentrating mill had been erected on Lake Huascacocha, below Tuctu, and a custom smelter at Yauli, in the main valley to the south. Later, a small smelter was built on Lake Huacracocha, just northwest of the mines.

Copper production on a modern scale, with silver as an important accessory, attended entry into the district of the Morococha Mining Co. in 1905 and of Backus y Johnston del Perú and other interests in 1906. Thus were afforded smelting facilities at La Fundición, Casapalca, and Rio Blanco; and Morococha quickly became the second copper producer in Peru. At present, besides the

Cerro de Pasco Copper Corporation, which now controls the above-mentioned companies, several companies with Peruvian capital are active, including the Alapampa, Puquiococha, Sacracancha, and other organizations. The modern smelter at La Oroya has superseded the other plants.

The exact production of the district is unknown, but from such information as is available the recent output is estimated as follows:

Metals produced in Morococha district, 1928–32

	Copper (pounds)	Silver (ounces)	Gold (ounces)
1928	57,849,642	2,443,262	4,566
1929	48,400,262	2,340,670	4,918
1930	42,141,030	1,826,463	3,984
1931	39,070,350	1,702,777	2,065
1932	33,101,936	1,451,890	1,965
	220,563,220	9,765,062	17,498

Because of the nature and distribution of the deposits, development of reserves far in advance of extraction is not advisable. But progressive improvement in understanding of ore occurrence has permitted ample reserves to be maintained, despite production, which, except during the depression years, has expanded rapidly.

Local geology

Geologic column

The rocks present in and immediately about the Morococha district are noted in the summary of regional geology in their general relations to the formations of the central Peruvian Cordillera. Those of direct importance in connection with ore occurrence are described below and are shown graphically in figure 62. The area shown in this diagram, about $2\frac{1}{2}$ by 3 miles, embraces most of the mineralized ground of the region. The main productive section extends from the neighborhood of Morococha Lake westward. The highest point on the surface, south of Lake Huacracocha, is 16,580 feet above sea level; the lowest, Lake Huascacocha surface, 14,300 feet. The base of the diagram is at 13,000 feet. The diagram has the same vertical as horizontal scale. This, together with the distant position of the viewpoint (13,800 feet above and 4.05 miles S. 55° E. from the surface at the near corner), allows only a faint suggestion of the extreme ruggedness and angularity of the topography. The drawing involves some generalization of the structure, which is known in accurate detail only at the surface and where mine workings exist. The rear block is simply pushed back to reveal the (simplified) three-dimensional relations where they are best known.

The Catalina volcanics, assigned to the Carboniferous, embrace effusive fragmental rocks and flows, with perhaps some intrusive sills, and range in composition from andesitic to rhyolitic, with latites and dacites predominating. Their folded beds of gray to pink and purplish color have undergone intense alterations in the vicinity of the mines.

The Potosi limestone (Jurassic) rests nearly or quite conformably on the Catalina, as gray, white, and buff beds of somewhat variable nature. Dolomitic and cherty zones are present; carbonaceous and iron pigments vary in amount.

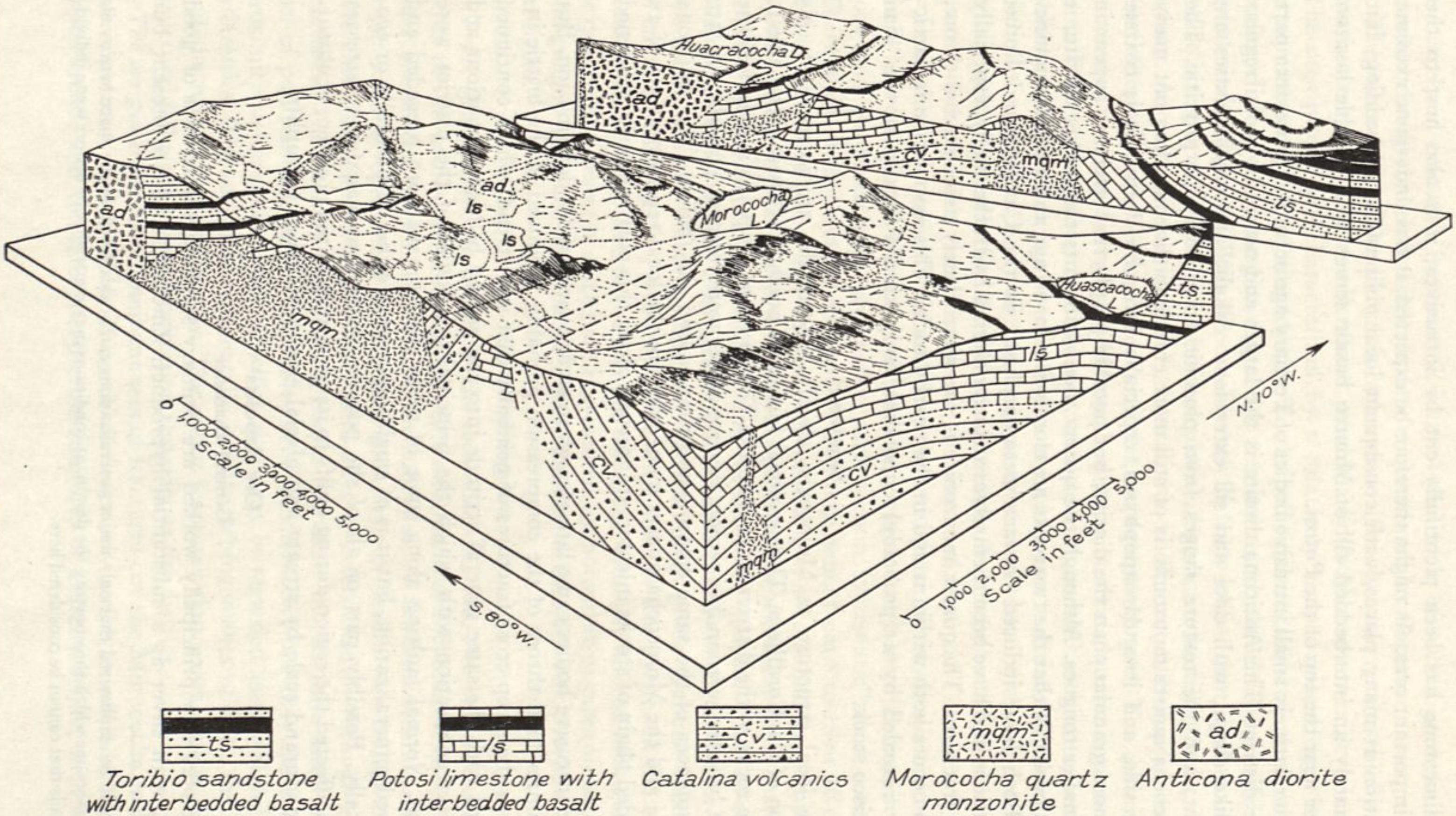

FIGURE 62.—Diagrammatic representation of Morococha, Peru.

This limestone has been plentifully cut by intrusives; it is also host to the most important ores. As might therefore be expected, it has undergone extreme alteration at many places, with consequent local obliteration of bedding; but fortunately an interbedded sill of Monteo basalt serves as a reliable horizon marker near the top of the Potosi.

Two relatively small intrusive bodies of Tertiary age occur in the western part of the district. The Anticona diorite is the larger and older. It is of irregular stocklike shape, with dike and sill extensions. Alkalic and silicic phases are present, and the texture ranges from plutonic to strongly porphyritic. The Morococha quartz monzonite is of still more erratic outline, sending out many dikes, sills, and irregular apophyses, especially into the Potosi. It is coarser and more granular than the diorite, but notably porphyritic variants appear in the smaller tongues. Although the quartz monzonite cuts the darker diorite, it seems probable that the two rocks are closely similar in age and are consanguineous. Both have induced contact metamorphism in the Catalina and Potosi formations and have been themselves strongly altered hydrothermally, especially along fractures. The quartz monzonite is the more closely associated with ore, which occurs both within it and in the nearby rocks. This association is particularly revealed by a (probably) cupolalike body known locally as the "San Francisco stock."

Structure

The local structure at Morococha clearly reflects the architecture of this portion of the Cordillera. Thus regional folding of north-northwest trend affects all the rocks of the district older than the Tertiary intrusives. As is likewise true in the broader surrounding region, reverse faults were formed, probably as late consequences of the same compression that caused the folding. The Anticona diorite and the Morococha quartz monzonite are the local representatives of an extended chain of stocks injected at intervals along this northwesterly weakened belt.

The intrusive bodies came late enough to escape most of the deformation. But the fainter final throes of the compression probably produced in the brittle intrusives the steep cross fractures of generally east-west trend, which continued onward with the same general attitude into the nearby bedded formations and in direct connection with which the principal ore bodies of the district were formed. Normal faulting along some of these cross breaks both preceded and followed mineralization, but it is of small importance either structurally or economically. Possibly part or all of the post-ore movement was due to stresses which affected the region during uplift to its present elevated position. Sculpturing on a grand scale by stream and glacial erosion followed the uplift.

Ore deposits[4]

General character

The ores now principally worked are primary sulphide copper ores of good grade, with silver as a substantial byproduct. Zinc and lead are present but

[4] It is to be emphasized that only major generalizations can be dealt with in the space here available. Assertions which thus portray the dominant conditions may contradict or distort some individual details that cannot be considered here.

are rarely of economic importance. Part of the ore is of such a grade as to be smelted directly; the remainder is first concentrated by flotation.

The mineralogy of the district is rather diversified, but this results chiefly from contact metamorphism and relates particularly to the nonmetallic minerals. The ores proper are characterized by a relatively simple mineralogy. In approximate order of declining abundance the principal metalliferous minerals are pyrite, chalcopyrite, enargite, magnetite, tennantite-tetrahedrite (argentiferous), sphalerite, and galena. Bornite occurs locally in fairly large quantities but on the whole is scarce. The same is true of specularite. Pyrrhotite is still more local and scanty. Aikenite (or wittichenite?), bournonite, cubanite, jamesonite, luzonite, matildite, and a few unidentified varieties are extremely rare. The distinctive mineral of the camp is enargite. Among the gangue minerals, quartz is most common. Calcite, ankerite, rhodochrosite, and siderite, as well as biotite, sericite, chlorite, and epidote, also occur. Barite is uncommon and fluorite rare. Large bodies of anhydrite partly altered to gypsum are associated with sulphides but rarely with commercial ore. In the limestone near the intrusives a varied suite of contact-metamorphic minerals appears, as discussed beyond.

From ore body to ore body and from place to place within single ore bodies there is pronounced variation in mineralogy, which occurs with change in wall rock and particularly in accordance with certain systematic zonal controls. There is also wide variation in gravity, the range being from 8 to 15 or 16 cubic feet to the ton in place. The densest ore, consisting of solid sulphides, comprises pyrite alone or pyrite mixed with varying proportions of chalcopyrite, enargite, tennantite-tetrahedrite, sphalerite, and occasionally galena. The so-called "llampo" ores, of slightly lower gravity, are of loose, sandy or sugary texture and run freely without blasting; they are relatively high grade granular mixtures of enargite, chalcopyrite, and tennantite with more or less pyrite. In the range from 10 to 12 cubic feet to the ton are sulphides with soft altered rock gangue or gouge. The lowest gravities are represented by porous aggregates of sulphide and gangue minerals, also sparser disseminations as complex stockworks of tiny stringers.

Structural features

Types of deposits.—According to the local classification, two broad structural types of ore bodies are recognized—veins and mantos. Included in the manto class are several structural variants or subtypes. A third structural unit of larger scale is represented by localized groupings of several ore bodies called "ore clusters." The veins, of course, were directly determined by through-going fractures. The mantos and related bodies represent more subtle selection of loci of permeability and of favorable chemical character; but they lie in close proximity to important veins, of which they may be regarded as specialized distributaries. The ore clusters generally involve arrangements of both the vein and the manto types of bodies. The major fractures thus exert a most direct structural influence on ore localization throughout the district.

The ore pattern.—Two dominant sets of fractures cut the Morococha rocks—the important reverse faults of north-northwesterly strike, parallel to the regional trend, and the later steep cross fractures of easterly strike, with some of which normal faulting of moderate displacement is associated. This combination cannot be called a "fracture system" in the strict sense, as the component sets are of different age and causation; but it does yield an intersecting (roughly rectangular) fracture pattern evident on surface and underground maps. It might therefore be expected that mineralization would have produced a vein pattern of corresponding figure. Such is not the case. The reverse faults have been only sparingly and locally utilized as sites of ore deposition; they may have induced and now contain minor spurs or swellings of ore bodies whose major localization was caused by other factors; but only rarely do they hold independent bodies. The cross fractures, on the other hand, or at least their principal representatives, have served as both channelways and receptacles and thus have not only received important vein deposits within or along themselves but have also given the mineralizing solutions access to nearby favorable loci of other kinds, thereby producing the manto class of ore bodies. Within the veins proper the mineralization was variable. Shoots of commercial ore, large or small, are separated by greater or less intervening stretches of lower grade or of worthless mineralization.

The ore pattern, therefore, comprises, as the dominating skeleton, a series of east-west veins carrying ore shoots and a somewhat more erratic distribution of bodies of the manto class, which, however, are generally located in obvious proximity to the veins, if not, indeed, as finlike lateral extensions directly therefrom. Where the ore shoots of one or more veins with or without nearby mantos are so bunched as to make a local collective unit, this becomes an ore cluster. Finally, on a still larger scale, there is a suggestion in the spacing of the ore clusters that they mark the intersections of a roughly rectangular network, of which one element consists of the eastward-trending veins and the other element, as yet uncertain, is probably some consequence of the north-northwesterly regional structure.

Vein structure and mineralization.—Considered in detail, the character of the fractures along which veins have been formed appears to depend upon (*a*) the intrinsic nature of the rock in which the fractures occur, (*b*) the state of structural complexity that had already been developed in the rock when the fracturing took place, and (*c*) the depth of the site of fracturing below the then existing surface. It is most convenient to discuss these influences and their consequences as exemplified in the major rock formations. And for the sake of brevity, the kind and abundance of mineralization associated with these structural variations may be considered concurrently, even though other than structural factors are involved.

In the quartz monzonite the fractures tend to be sharp, clean-cut breaks, as would be expected in a crisp, brittle rock. This is especially true of the larger monzonite masses. Near the present surface individual nearby fractures of approximately parallel trend are bound together by a multiplicity of minor branches and crisscross connecting stringers. The resulting veins or lodes are well and rather uniformly mineralized. In the earlier years of the modern operating period ore was derived chiefly from these conspicuous veins in monzonite, especially within the San Francisco stock, which has a diameter at the surface of about one-third of a mile. With increasing depth the vein structure becomes simplified: single veins rather than a lodelike complex become the rule. At the same time, the central portion of the stock tends to become less productive. On the deep levels simplification goes still further: only the strongest of the fractures retain structural importance, and commercial ore mineralization is chiefly concentrated in shoots at the borders of the stock near the limestone contacts. Although thermal and chemical influences undoubtedly played a part in this localization of profitable mineralization, structural conditions as well have obviously contributed to its accomplishment.

In the diorite stock to the west the vein structures appear generally similar to those of the quartz monzonite, but the mineralization is feebler and is characterized more by lead and zinc than by copper and silver. Therefore development and study have been limited.

In the Catalina volcanics, which likewise are, for the most part, brittle rocks, the vein structures have general resemblance to those in the quartz monzonite. Silver and lead were produced from some of these veins in earlier years, and they were long regarded as unfavorable to copper-silver mineralization; but more recently important copper shoots have been opened at favorable positions at greater depth than had previously been explored.

The limestones appear to have behaved toward the fracture-forming stresses as weaker and less brittle rocks than the igneous varieties already mentioned. The individual veins in limestone extend without interruption for longer distances; they are also simpler and more unified, and many of the complexities they exhibit tend to disappear with depth. Where strong, they comprise zones of parallel breaks instead of the interlacing fractures seen in the monzonite; moreover, they may carry heavy gouge, though apparently the amount of dislocation along them is slight. Traced along strike any of these limestone veins may abruptly pinch down to insignificance. The mineralization, though abundant, was localized in a more erratic manner than in the monzonite, apparently owing in part to chemical differences within the limestone.

The ore shoots of the veins in all the rocks apparently tend normally to assume elongate form and to stand at rather steep angles of plunge; but form and attitude may be modified by structural or compositional influences in the rock forming the vein walls.

Manto structures.—The term "manto," originally applied on the basis of form, has in most Latin-American countries come also very commonly to imply deposition by selective replacement of a given bed or layer. At Morococha these connotations of the term have been recognized; but the local ore structures have injected another concept, which has somewhat warped the word to cover those bodies in limestone not classed as veins. Five structural varieties are thus included—true mantos, pipes, manto-pipes, sill ore bodies, and contact ore bodies. In all these varieties replacement was the dominant process of deposition. Nevertheless all of them are so closely connected with through-going vein fractures as to indicate plainly how the solutions reached them.

True mantos, pipes, and manto-pipes: True mantos and pipes are closely related and merge into one another. The true manto is tabular and lies with the bedding, which was the controlling factor. (See fig. 63.) The pipe, instead, is elongate and crosscuts the bedding along some transecting structure such as a minor fracture or joint; these localizing fractures are often roughly parallel to the reverse faults and may possibly be sympathetic therewith. (See fig. 64.) Still more common than either is the manto-pipe, a composite or intermediate type. Instead of forming a single ore shoot, like the true manto or the pipe, the manto-pipe is of more or less interrupted continuity. In general form and attitude it is pipelike, as it crosscuts the bedding; but in detail it is a succession of small true mantos arranged vertically or steeply en échelon above one another, with connecting vein mineralization. The dominant localizing factor seems, as in the pipe proper, to have been a transverse break, but extension laterally into favorable beds outweighed a deposition in its immediate walls. (See fig. 65.)

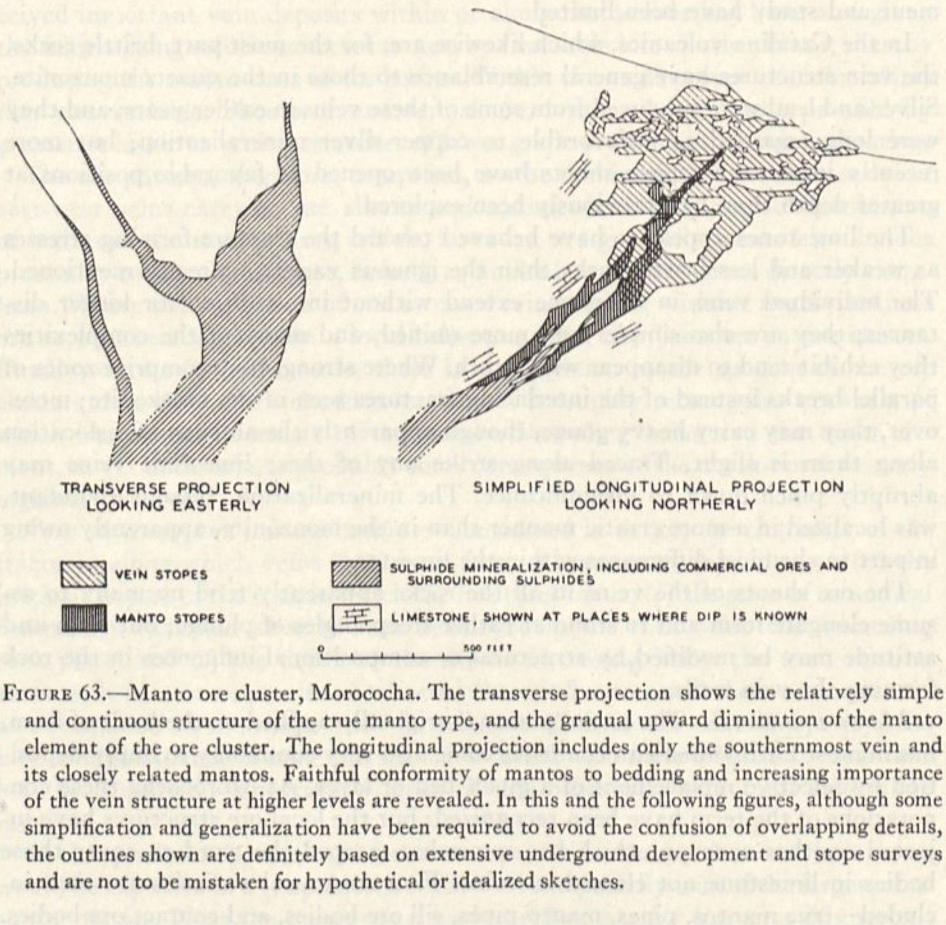

FIGURE 63.—Manto ore cluster, Morococha. The transverse projection shows the relatively simple and continuous structure of the true manto type, and the gradual upward diminution of the manto element of the ore cluster. The longitudinal projection includes only the southernmost vein and its closely related mantos. Faithful conformity of mantos to bedding and increasing importance of the vein structure at higher levels are revealed. In this and the following figures, although some simplification and generalization have been required to avoid the confusion of overlapping details, the outlines shown are definitely based on extensive underground development and stope surveys and are not to be mistaken for hypothetical or idealized sketches.

Sill ore bodies: Where limestone penetrated by a sill of monzonite—both dipping at a considerable angle—is cut across its strike by a vein fracture, an ore body of the manto type may form in the limestone lying immediately on the hanging-wall side of the sill. Such bodies may have a considerable continuity along the dip. Where the sill pinches out or is otherwise cut off up the dip, the ore body may continue upward, nevertheless, as a true manto; or where the up-

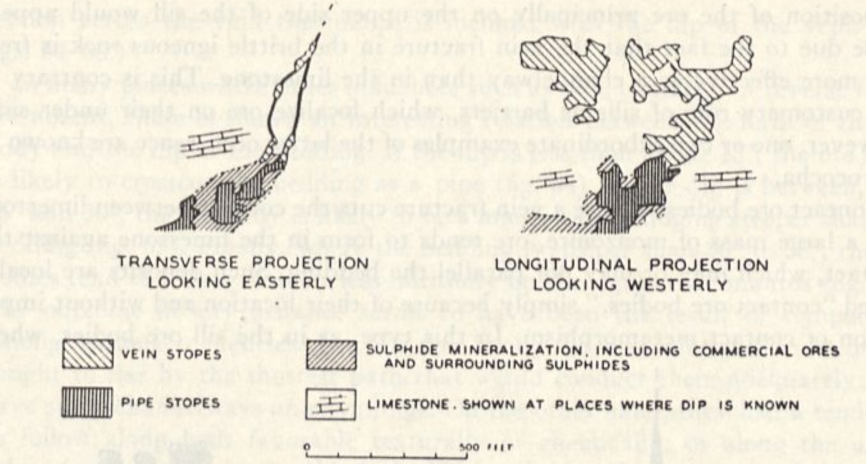

FIGURE 64.—Pipe ore cluster, Morococha. The transverse projection illustrates the primary control by the vein fractures. Both views show crosscutting of bedding by the ores and the upward change in importance from the pipe element to the vein element in the continuous ore cluster.

ward extension of the dip flattens abruptly, the ore body may forsake the sill and continue thence upward as a pipe or manto-pipe. A few similar examples occur on the upper side of inclined sills of basalt. (See fig. 65.) It seems probable, therefore, that ore localization of this kind was essentially a structural influence and that the sill itself has no significance as the immediate source of the ore.

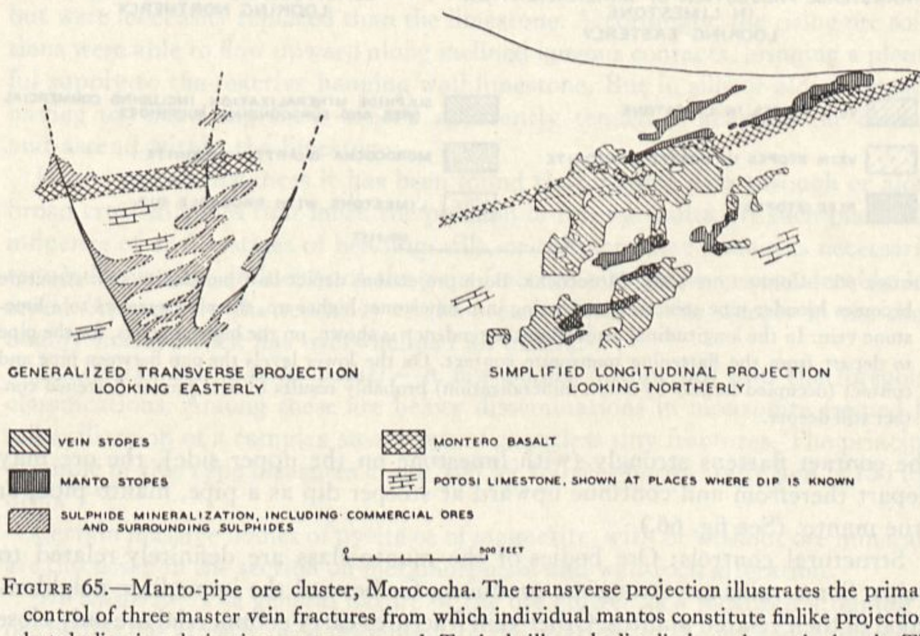

FIGURE 65.—Manto-pipe ore cluster, Morococha. The transverse projection illustrates the primary control of three master vein fractures from which individual mantos constitute finlike projections but decline in relative importance upward. Typical sill ore bodies lie just above the basalt. The longitudinal projection, necessarily greatly simplified, shows only stopes on the center vein and on the mantos in its immediate north wall. The en échelon linking of these small mantos produces the larger manto-pipe structure.

Deposition of the ore principally on the upper side of the sill would appear to be due to the fact that the vein fracture in the brittle igneous rock is freer and more effective as a channelway than in the limestone. This is contrary to the customary rôle of sills as barriers, which localize ore on their under side. However, one or two subordinate examples of the latter occurrence are known in Morococha.

Contact ore bodies: Where a vein fracture cuts the contact between limestone and a large mass of monzonite, ore tends to form in the limestone against the contact, which may or may not parallel the bedding. Such deposits are locally called "contact ore bodies," simply because of their location and without implication of contact metamorphism. In this type, as in the sill ore bodies, where

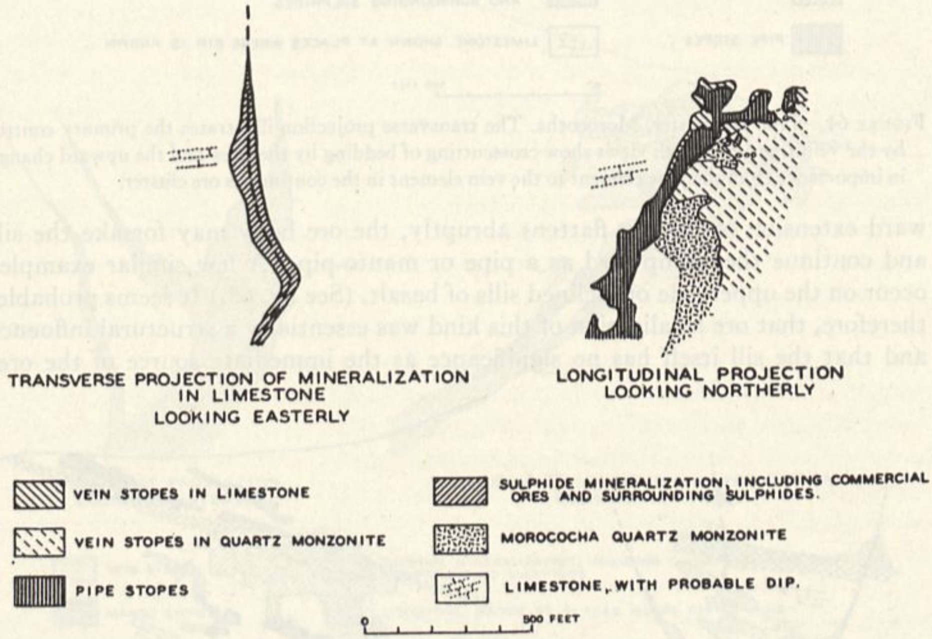

FIGURE 66.—Contact ore body, Morococha. Both projections depict how monzonite vein structure becomes broader pipe structure on passing into limestone; higher up, the pipe narrows to a limestone vein. In the longitudinal projection the tendency is shown, on the highest levels, for the pipe to depart from the flattening monzonite contact. On the lower levels the gap between pipe and contact (occupied largely by skarn mineralization) probably results from a similar flattened contact still deeper.

the contact flattens strongly (with limestone on the upper side), the ore may depart therefrom and continue upward at steeper dip as a pipe, manto-pipe, or true manto. (See fig. 66.)

Structural controls: Ore bodies of the manto class are definitely related to veins. Some veins are strong ore producers far beyond the immediate neighborhood of their related mantos. Other vein fractures carry commercial ore only close to the places where mantos adjoin. Invariably a vein or a fracture appears to have acted as feeder for the manto. Thus in the plane of the vein the inclination of the manto is controlled by contact, sill, or bedding, while in the vertical projection across the vein the manto is inclined with the dip of the vein. (See figs. 64–66.)

In many places where other influences such as sills, contacts, or reverse faults are absent, there is shown an interesting relation between the form of the ore body and the dip of the bedding. If the dip is less than about 15°, the ore body is likely to crosscut the bedding as a pipe (fig. 64). If the dip is between, say, 15° and 30°, the ore body is likely to be a manto-pipe plunging steeper than the bedding (fig. 65). Finally, where the bedding is steeper than 30° to 35°, the ore bodies tend to follow more or less faithfully up the dip as true mantos (fig. 63). The outcome in any instance seems to have been the result of competition among various tendencies. On the one hand, the ore solutions undoubtedly sought to rise by the shortest path that would conduct them adequately; this gave steep channelways an advantage. On the other hand, they had a tendency to follow along beds favorable texturally or chemically, or along the under sides of relatively impermeable beds. Where the bedding was steep, both tendencies were easily satisfied and the true manto resulted. As the dip became flatter there was increasing incentive for the solutions to desert the bedding in favor of such steeper cross avenues as were available. This balance was probably a pretty delicate affair, easily upset by factors as yet unknown.

The influence of sills and larger monzonite masses (and, indeed, of the basalt sills also) fits rationally into this general scheme of control. It is found that they have had a tendency to prolong the true mantos and sill ore bodies up the dip. The monzonite and the basalt had a propensity to form clean permeable fractures but were less easily replaced than the limestone. Accordingly, the rising ore solutions were able to flow upward along inclined igneous contacts, bringing a plentiful supply to the reactive hanging-wall limestone. But in sills or along contacts having too flat a dip the solutions apparently tended to abandon the contact and ascend within the limestone.

In one or two instances it has been found that mantos pass through or along broad crushed zones that mark the position of reverse faults. At such places the influence of any vestiges of bedding, sills, or contacts that remain is necessarily reduced; even the influence of the vein fracture may be very considerably lessened. Apparently the tendency of the ore solutions to rise steeply in the thoroughly mashed rock has overwhelmed all others.

Stockworks and massive bodies.—A few bodies do not fall into the foregoing classifications. Among these are heavy disseminations in monzonite formed by mineralization of a complex stockwork of countless tiny fractures. The principal example of this type measures about 100 by 150 feet horizontally and is 150 feet deep.

Certain massive bodies of pyrite or of magnetite, with or without ore minerals, are discussed in the section on metamorphism and wall-rock alteration.

Ore clusters.—The general nature of the ore cluster as a localized grouping of ore bodies has already been presented. In the relations of the individual elements to the cluster as a whole, the most conspicuous feature is the tendency toward downward convergence and merging, as of upper branches into a trunk below. This tendency is manifested in different degrees in different examples (see figs.

63–66), but the suggestion arises that the several bodies comprising the cluster were probably fed from a common underlying throat.

Ore clusters in limestone: It is in limestone that the local crowding of ore bodies that produces the ore cluster finds best and commonest expression, for to the several ore shoots that may be closely spaced in one or more nearby bodies there may be added a number of bodies of the manto class. In limestone, also, the downward convergence of the component bodies of the cluster is best exemplified. At depth the ore cluster in limestone is comparatively small, compact, and rich. It consists mostly of manto mineralization, the recognizable vein component being subordinate. Upward, the structure becomes more complicated. There is a branching outward along vein fractures, and mineralization in shoots along these fractures becomes progressively dominant over the manto replacements. Gradually the mantos cease to extend across from one master vein feeder to the next, and only the most favorable beds carry mantos. Eventually, only the veins remain, and finally even they carry no noteworthy mineralization.

In size the clusters vary widely. In one cluster the diameter at the maximum cross section was 160 feet and at the minimum only 50 feet, with a total productive height of 500 feet. Another cluster is over 1,000 feet across near the surface, is 300 feet across nearly 1,000 feet below, and has shown practically undiminished production throughout that vertical interval.

Distribution of the ores was adjusted to a complex structural set-up that antedated the present topography. The individual ore clusters therefore show variable relation to the existing erosion surface; some have lost their upper portions, and the tops of others are being found on the deeper levels.

Concerning the bottoms of the ore clusters, comparatively little has yet been disclosed. One cluster, however, has been indicated by development to pass downward into monzonite that appears to have the form of a small, sharp cupola; and in a similar example the monzonite occurs as a group of closely packed sills; in both these cases the richness falls markedly in the monzonite. It is not yet known whether the other ore clusters in limestone will eventually be found connecting downward with up-reaching apophyses of monzonite. Neither is it fully understood, in the specific examples just mentioned, why the rich ore clusters should, as it were, sprout out of monzonite cupolas; but the information at hand suggests rather that favorable fracturing and other fortunate conditions of permeability were associated with these up-thrust extensions of the underlying monzonite than that the ore materials were derived by direct local emanation from that part of the monzonite embraced by these tongues.

Ore clusters in monzonite: The San Francisco stock is the most notably mineralized body of monzonite, and the only one in which the disposition of mineralization justifies the term "ore cluster." Within the stock itself veins are the only producers; the general distribution of the ore shoots on these has already been mentioned. Contact ore bodies are formed in the limestone at places where the veins leave this stock, and these marginal ore bodies may be regarded as belonging to the same cluster as the vein shoots within the monzonite. The cluster as so regarded, however, does not exhibit the downward convergence characteristic of clusters wholly in limestone, but instead shows divergence, occasioned by the downward enlargement of the stock.

In the Catalina volcanics and in the Anticona diorite the mineralization was too sporadic to produce any marked clustering of ore shoots.

Metamorphism and wall-rock alterations

Throughout much of the mineralized area at Morococha rock alteration has been intense. Even at distances as great as hundreds of feet from known ore or any obvious channelway, limestones, volcanics, and intrusives are frequently found so thoroughly altered as to be indistinguishable without resort to the microscope. Two general types of change have affected the rocks—contact metamorphism and hydrothermal alteration. Regional or dynamic metamorphism is virtually absent, because, despite strong folding, none of the rocks exposed within the district have experienced such depth of burial as to undego those high-pressure changes. Weathering has produced only restrained and unimportant effects.

Contact metamorphism.—On the surface broad bands of metamorphosed limestone reaching 250 feet or more in width adjoin the contacts of the quartz monzonite for long distances. These bands are mainly independent of the bedding, but here and there smaller areas of similar alteration lying within normal limestone indicate selective attack on susceptible lenses or beds. Similar contact zones are encountered at many places underground.

Diopside, andradite, and tremolite are the principal nonmetallic minerals of these alteration zones; they may occur as mixtures, or any one may form large masses little contaminated by other species. Wollastonite, hedenbergite, actinolite, epidote, clinozoisite, and serpentine are of variable but generally subordinate abundance, and vesuvianite, ludwigite, scapolite, zoisite, and andalusite are among the relatively rare varieties. As is so commonly true elsewhere, quartz is a minor component of the contact zones. Magnetite and pyrite are very abundant locally, either as separate masses or mixed with one another or with the nonmetallic minerals. Specular hematite and pyrrhotite are less plentiful. All these metalliferous minerals are later than the contact silicates and, on the whole, occur farther from the intrusive contacts. Sulphides of the ore metals may be scattered through the iron sulphides and oxides but not in economic quantities.

In addition to the entirely typical manifestation of contact metamorphism (pyrometasomatism) just described, there are some occurrences of less conventional nature. Although the Catalina volcanics, because of their effusive nature and their earlier age, were incapable in themselves of inducing contact metamorphism in the limestone, nevertheless their contact with the Potosi is at several places marked by noteworthy bands of strong alteration of a kind evidently belonging in the pyrometasomatic category. The preponderant constituents of these altered bands are magnetite and pyrite; the typical silicates of the monzonite-limestone contacts are subordinate or wanting. This somewhat anomalous state of affairs invites explanation.

Where monozonite has directly invaded the volcanics the contact effects on the latter are relatively slight: tremolite in sparse radial aggregates is the most distinctive product, though some chlorite and epidote may have related origin. As contrasted with the limestones, this scantiness of contact alteration in the volcanics may conceivably be due either to insufficient emanations from the monzonite at just these places, or else to relative inertness of the volcanics toward the available emanations. The latter explanation, which seems the more probable, would imply that mineral materials not precipitated in and by the volcanic rock could pass on through it and, if reaching susceptible limestone beyond, before losing too much of their heat and pressure, could there bring about important alteration. In short, the layer of volcanics separating the monzonite from the limestone would act as a relatively inert but permeable sieve or screen. The alteration produced in the limestone by monzonite emanations that had passed through the screen would naturally be expected to show similarities to the alteration produced where limestone lies directly against monzonite but would have a lower order of intensity because of losses of heat and pressure and some compositional changes in the passage through the screen.

Bearing in mind that magnetite and pyrite are the feebler and more outlying representatives of pyrometasomatism in the monzonite-limestone contact zones and that these are the dominant minerals of the limestone alteration bands along the Catalina contacts, one is led to entertain the possibility that these alteration bands represent, indeed, a sort of remote pyrometasomatism. There appears to be a distinct analogy between the development of magnetite and pyrite in limestone separated from monzonite by a layer (of volcanics) that was initially inert to the emanations and the development of magnetite and pyrite in limestone separated from monzonite by a layer (of metamorphic silicates) that has just previously been rendered inert to the emanations.

The foregoing explanation of the alteration at places along the Potosi-Catalina contacts must receive further study of existing and additional underground openings before it can be regarded as more than a suggestive hypothesis.

Hydrothermal alteration.—Change in the wall rocks occasioned by undoubted hydrothermal action, although influenced both by the kind of rock involved and by distance from the principal channelways of ingress, nevertheless possesses a recognizable unity throughout. In monzonite the dominant alteration products are quartz, sericite, and epidote-chlorite, in order going away from major veins, with pyrite likely to be plentiful with any of these gangues. In Catalina volcanics the mineralogy and arrangement are similar, with the addition of some carbonate—siderite-rhodochrosite close in and calcite fartherout. In Potosi limestone the series is quartz and siderite-ankerite-rhodochrosite-dolomite, then biotite, and finally chlorite and some epidote, with pyrite more abundant in the nearer than in the farther phases. It is to be understood that the indicated spatial distributions are merely general overlapping tendencies rather than sharp and invariable successions. Chlorite is the most plentiful and the most pervasive of the alteration products.

It is with alteration of this definitely hydrothermal type that the commercial ores occur; and as they are located as veins in or as mantos closely adjoining the major channelways, it follows that the ore bodies and ore clusters commonly lie as bullseyes in surroundings of outward-fading alteration. Indeed, it is impossible to regard the ore minerals as separate from the products of rock alteration, just as it is difficult here to draw rigid demarcation between the deposits laid down in open spaces and those formed by replacement.

The genetic relationship between these hydrothermal alterations and the pyrometasomatic alterations is evidently intimate but is not entirely clear. Few veins of commercial importance occur in strongly contact-metamorphosed limestone. Ores in limestone may occur close to monzonite, but as a rule only if pyrometasomatism is there feeble or absent; where notable pyrometasomatism has occurred, ores in the limestone are generally found only still farther away from the monzonite. These facts suggest a degree of mutual exclusiveness betwen pyrometasomatism and the combination of commercial ore deposition with attendant hydrothermal rock alteration. Nevertheless, ore in limestone, when followed (downward or otherwise) in the direction of increasing intensity, is often found to become progressively more pyritic and then may begin to acquire magnetite and in some places skarn silicates; the commercial quality of the ore generally ceases where such changes become really important.

Magnetite and pyrite, the outlying representatives of pyrometasomatism, would seem to be also the inlying representatives of the obviously hydrothermal deposition. Stated otherwise, there might be established the following idealized progression of depositions from a given lot of emanated material moving outward or upward in the limestone: (1) Contact-metamorphic silicates; (2) magnetite-pyrite; (3) sulphide ores with hydrothermal gangues; (4) feebler phases of hydrothermal gangues.

In short, the replacement deposits dominated by magnetite-pyrite may represent the transition between the strictly pyrometasomatic and the obviously hydrothermal deposits.[5] This would accord with the explanation already suggested for the magnetite-pyrite alteration bands along the Potosi-Catalina contacts.

However, certain features do not entirely harmonize with the conception thus set forth. Typically hydrothermal ore-bearing veins of fairly moderate intensity-character occur within the same masses of monzonite that cause contact metamorphism at places along their contacts with limestone. At one or two localities, moreover, the vein mineralization continues beyond the monzonite boundary out into walls of pyrometasomatized limestone. These occurrences suggest that the timing of the entire mineralization episode may not have been as simple as the foregoing conception might imply.

Supergene alteration.—Presumably the Morococha deposits are of about the same age as those at Cerro de Pasco and therefore probably became truncated by a surface of low relief. If so, the Morococha ores that outcropped on that surface doubtless suffered the same strong oxidation and the same sulphide enrichment at favorable places as the ores at Cerro de Pasco still reveal upon a present surface but slightly modified from its earlier state. But Morococha, lying within

[5] That pyrometasomatism may be regarded as only a special high-intensity phase, in limestone, of normal hydrothermal activity has been proposed elsewhere (17, p. 531). See also Wandke, Alfred, and Moore, T. G., Pyrometasomatic vein deposits at Tepezala, Mexico: Econ. Geology, vol. 30, no. 7, pp. 765–782, 1935.

the zone of maximum disturbance attending the enormous Andean uplift, has since suffered such extreme erosional carving that no positive traces of the older gentle topography remain, nor more than scanty vestiges of the associated weathering products.

Insignificant quantities of oxidized ores were encountered erratically in the early days of shallow workings. In the upper levels of the modern mines chalcocite and occasionally covellite are seen here and there, chiefly as coatings on the other sulphides; but rarely is there found any sign of a limonitic zone of leaching. It therefore seems probable that this faint enrichment mainly represents the residual dwindling roots of an enrichment produced with respect to the earlier, higher land surface.[6] A noteworthy but restricted feature of this enrichment is the partial replacement of large bornite crystals by chalcocite, with the production of beautiful graphic and grating patterns of these two minerals; supergene chalcopyrite also accompanies the chalcocite in slight amount.

Probably the whole of the district was not long ago covered by ice.[7] The present valleys show profound shaping by glacial erosion; the mid-slopes embrace cirques, moraines, talus débris, or plucked and scoured surfaces; and the higher summits are still ice-clad. Since the disappearance of this general ice mantle the time has been so short and the temperatures so low that chemical weathering has been outstripped by vigorous mechanical degradation. Ferruginous and manganiferous carbonates have become darkened by oxidation right at the surface, but magnetite and sulphides are practically unchanged.

Mineral zoning

From what has already been said as to character and distribution of ore and rock alteration, it will have been seen that Morococha affords a noteworthy illustration of zonal arrangement. The zoning is very obvious horizontally: the center of the district yields chiefly copper and copper-silver ores; the silver-lead ores of earlier production came from mines located somewhat farther out; and still farther away mineralization at last dies out as occurrences of lead-zinc. With this distribution of the metals goes a corresponding outward decline in intensity-character of the gangue and rock-alteration minerals, starting from those of pyrometasomatic character.

Vertical zoning is no less evident and can be more carefully studied because often exemplified within a single mine. This phase of mineral variation is best shown by the ore clusters in limestone. Where these have been adequately explored vertically they exhibit a common tendency toward the following (somewhat idealized) succession of dominant ore minerals, stated from below upward: Heavy pyritic material, often with magnetite; pyrite and chalcopyrite; pyrite, chalcopyrite, and enargite; pyrite, enargite, and tetrahedrite-tennantite; tetrahedrite-tennantite and sphalerite; sphalerite and galena. In terms of metals this sequence more definitely and fully repeats the district zoning shown horizontally

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[6] Compare similar conditions at the Superior mine, in the Engels district, California (Econ. Geology, vol. 12, pp. 33–37, 1917).

[7] For an interesting and peculiar example of glacial erosion close to Morococha, see Harvey, R.D., Glacial chutes from the Peruvian Cordillera: Am. Jour. Sci., 5th ser., vol. 21, pp. 220–231, 1931.

—namely, iron, iron-copper, copper-silver, silver-zinc, silver-lead, and zinc-lead. And there is more or less evident a corresponding lateral or marginal zoning revealed by the individual ore clusters. Near the spreading tops of the ore clusters this lateral zoning covers a corresponding considerable area; but with lessening of cross section with depth, the commercial ore finally descends as a sheath around an expanding central core of pyrite.

The vertical scale varies in these examples of vertical zoning. For example, in one cluster the range from low-grade lead-zinc down through silver and copper ores to low-grade pyrite was embraced within 500 feet vertically. In another cluster where mining started at the surface in copper-silver ore, the workings are still in good copper ore 1,000 feet below. As a rule, and as would be expected, the smaller, feebler shoots and clusters show more rapid vertical change than those which are large and vigorous. Naturally, structural variations and changes in country rock also occasion departures from ideal uniformity. In certain places the zonal variations can be linked in subdued degree with relative distance from known protuberances of the monzonite; a more general influence is probably distance from the main upper surface of the generally underlying monzonite body. Finally, the accidents of position with respect to the present irregular erosion surface further prevent vertical equivalence among the respective portions that remain in the various clusters.

Origin

Source.—The space relations of the ores and attendant alterations to the indicated outlines of the quartz monzonite stock and the concentric zoning of the ores about the stock strongly suggest that the source of the ores was the quartz monzonite magma chamber. The age relations likewise support this conclusion. Noteworthy in this connection is the fact that although Anticona diorite produced borders of contact-metamorphic silicates at numerous places where it cut limestone, its emanations did not produce any mineralization of economic interest—at least within the range of present observation. Moreover, the centrifugal manifestations of zoning with respect to the quartz monzonite display the same declining intensity characteristics where they approach and enter the diorite as where they depart similar distances in other directions from the monzonite. It seems clear that, despite the probable consanguinity between the two intrusives, the later stage of differentiation which yielded the quartz monzonite was much the more suitable for the release of abundant mineral-forming emanations.

Depth of formation.—The position of the surface at the time of ore formation can be but vaguely inferred. Extrapolation of stratigraphic data from outside the district suggests that some 22,000 feet of later formations are missing at Morococha. How much of this indicated deficiency is due to erosion and how much to failure of deposition is unknown. Neither is it known how much of the erosion preceded Tertiary intrusion and ore formation. The fact that the diorite is in places notably porphyritic suggests that its cover was not excessive (though this also is difficult of evaluation in feet); its possible surface equivalents may have somewhat increased this depth of cover for the more plutonic quartz monzonite and the ores. But no sign of explosive fragmentation of either rock is preserved, Morococha thus contrasting with Cerro de Pasco.

The most important mineralization seems to belong mainly on the lower side of the boundary between the mesothermal and the leptothermal zones; some pyrometamorphism indicates still greater intensity; on the other hand, the shallower outlying ores are of feeble leptothermal character. Because of the probable rather restricted vertical distance between the top of the quartz monzonite and the then existing surface, the ores disclose a fairly rapid change in character vertically, suggesting a mild telescoping (17, pp. 538, 544).

The Morococha ores belong in about the same depth-intensity category as those at Cerro de Pasco—probably a little deeper. They are very distinctly of higher intensity-character than those at Casapalca (15, p. 519; 17, p. 520), only a few miles to the southwest.

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The Quiruvilca district, Peru

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Introduction

The Quiruvilca district is on the west side of the Cordillera Occidental near its crest, at the head of the Moche Valley, at an altitude of about 13,000 feet. It is in the Province of Santiago de Chuco, in the Department of Libertad. The district is reached by way of the Moche Valley from the port of Salaverry, a distance of about 130 kilometers. The distance from Salaverry to Quirihuac is about 40 kilometers by railroad. Thence there is an automobile road of 40 kilometers to Samne, the headquarters of the Northern Peru Mining & Smelting Co. From Samne to Shorey, the smelter for the Quiruvilca ores, is an aerial tramway over 40 kilometers in length. A 3-kilometer aerial tramway connects the Shorey smelter with the Quiruvilca mines, and its extension for another 5 kilometers reaches the Tertiary anthracite mines at Callayucan.

The climate and topography of the district are those of the high Andes. Radiation is great, so that days of sunshine are comfortable, and the nights are cold. The relief is moderate, characteristic of the high Andes, less than 250 meters generally. An area of rugged topography with high relief lies to the west of the district, at lower altitudes.

The district is an old one in which mining operations had been carried on for many years in a more or less desultory manner and on a small scale. The earlier operations had silver ores as their primary object, and the copper content was disregarded and not recovered. After 1895 more attention was paid to copper, and the output was largely argentiferous copper ore. In 1921 the Northern Peru Mining & Smelting Co. began developing the district for large-scale mining. The smelter and mill at Shorey were completed in 1927, and the aerial tramway to Samne in 1928. In 1928 also a sintering plant was added at Shorey. The Quiruvilca property is now equipped to produce 20,000 tons of ore monthly, but operations have been suspended during the depression.

The production reported by the Dirección de Minas y Petróleo during the years 1929 to 1931 was as follows:

Year	Gold (kilograms)	Silver (kilograms)	Copper (metric tons)
1929	239	14,223	10,122
1930	241	15,886	9,708
1931 (to August)	184	11,773	6,412

Geology

The country rock of the Quiruvilca district consists of hornblende and augite andesite flows, tuffs, and breccias that deeply cover the underlying Cretaceous sediments. The veins are confined entirely to the volcanic rocks.

The veins

The copper veins occur in a small portion of a large mineralized area within which there is considerable diversification in the content of the veins. There are three mineralized areas in the larger district—a southern group of silver veins with quartz filling, a central group of enargite and tetrahedrite veins, and a northwesterly group of silver veins with barite gangue. Some of the silver veins contain much galena and sphalerite.

The operations of the Northern Peru Mining & Smelting Co. have centered largely on the copper group. These veins have an east to northeast strike and a southerly dip. The wall rock is highly altered and impregnated with pyrite. The filling consists mainly of pyrite and enargite, some tetrahedrite, and very little gangue.

The principal vein is the Elvira, which was denounced in 1906 and was immediately recognized as a vein of unusual richness. Hand-sorted ores shipped from this vein in 1907 to 1909 ranged from 35 to 42 percent of copper. Malaga Santolalla gives several assays of the ore which range from 2½ to 11 ounces of silver to the ton and 9.5 to 39 percent of copper. The gold content runs less than one-third of an ounce to the ton. The later large-scale developments yielded ore averaging 3 ounces of silver to the ton and more than 5 percent of copper. The Elvira vein averages around 1 meter in width but locally widens to 3 meters. It is characterized by rich streaks, 0.2 to 0.4 meter wide, in which the tenor runs up to more than 25 percent of copper. The Elvira vein is cut and offset by the Morococha fault, which is also mineralized.

The zone of oxidation rarely extends deeper than 6 to 20 meters. This has been leached of copper and carried rich silver ores. Below it are the pyrite-enargite-tetrahedrite ores.

These copper veins are notable for their persistence in strike and mineralization. The Gildemeister and Almirante groups are over a mile long, with an interruption of only about 200 meters in the center.

Treatment

The coarser ore is smelted direct. The finer ore is concentrated by selective flotation and sintered at Shorey before going to the blast furnace.

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Malaga Santolalla, F., Estado actual de la minería en Quiruvilca: Cuerpo ing. minas del Perú Bol. 75, 48 pp., 1909. This is the only detailed description of the district. It contains a map of the region between Quirihuac and Quiruvilca on the scale of 1:300,000, a plan of the Elvira mine, and a claim map of the district on the scale of 1:25,000.

EUROPE

Kupfererzlagerstätten in Österreich

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Aus der Kartenbeilage ist ersichtlich daß die meisten und auch die ertragsreichsten Kupfererzlagerstätten Österreichs in der Grauwackenzone liegen welche aus paläozoischen Schichten mannigfach zusammengesetzt ist. Sie erstreckt sich erzführend vom Ostende der Alpen bis nach Vorarlberg zwischen den nördlichen Kalkalpen und der Zentralzone. Nur wenige, zumeist kleinere Vorkommen liegen außerhalb derselben, teils in der Schieferhülle der Tauern, teils in dem südlich davon gelegenen Altkristallin Kärntens und den paläozoischen Schiefern des Drautales.

Die oft bedeutende Mächtigkeit der isoklinalen Schichtfolge der Grauwackenzone ist großenteils durch Schuppenbildung, Überschiebungsbau und Faltung verursacht, wodurch auch die Form der Lagerstätten beeinflußt wird. Die Mineralisation breitet sich oft entlang Gleitflächen aus, oder in tektonischen Linsen (Metasomatose tektonischer Kalklinsen, etc.). Die Bildung der meisten Lagerstätten, besonders der gangförmigen, ist nach neueren Untersuchungen jünger als die kretazische Gebirgsbildung. Die Lagerstätten wurden aber noch von späteren Verwürfen, Blattverschiebungen und damit verbundenen strukturellen und mineralischen Umwandlungen betroffen. Die Kupfererzlagerstätten der Grauwackenzone sind teils echte Gänge und Gangnetze, teils lagerartige epigenetische Bildungen.

Für die genetisch einheitliche Vererzung der Zone sind Siderit, Kupferkies, Fahlerz und Zinnober charakteristische Bestandteile, welche jedoch quantitativ in sehr verschiedenem Verhältnis an den einzelnen Vorkommen beteiligt sind. Im östlichen Bereiche entwickelt sich zumeist der Spateisenstein zum vorherrschenden Bestandteil (Eisenerzer Erzberg, etc.) während in dem mittleren Teil der Zone Kupferkies, im westlichen Fahlerz den wirtschaftlichen Charakter der Lagerstätten bestimmen. Überhandnahme des Schwefelkieses kann diesen örtlich und zeitweilig zum Hauptgegenstand des Bergbaues machen (z. B. Oeblarn und Kallwang), weshalb manche derselben in dem Werk „Les réserves mondiales en pyrites" besprochen sind (Panzendorf u.a.). Dasselbe gilt für den hohen Silbergehalt einzelner Vorkommen (z. B. Röhrerbühel).

Unter den mengenmäßig unbedeutenden, aber meistens vorhandenen Nebengemengteilen wie Arsenkies, Magnetkies, Bleiglanz, Zinkblende und verschiedenen Nickel- und Kobalterzen werden die beiden letztgenannten ausnahmsweise auch abbauwürdig. Als Gangart erscheinen Eisenkarbonat und Quarz, daneben auch Baryt und verwandte Sulfate und Karbonate.

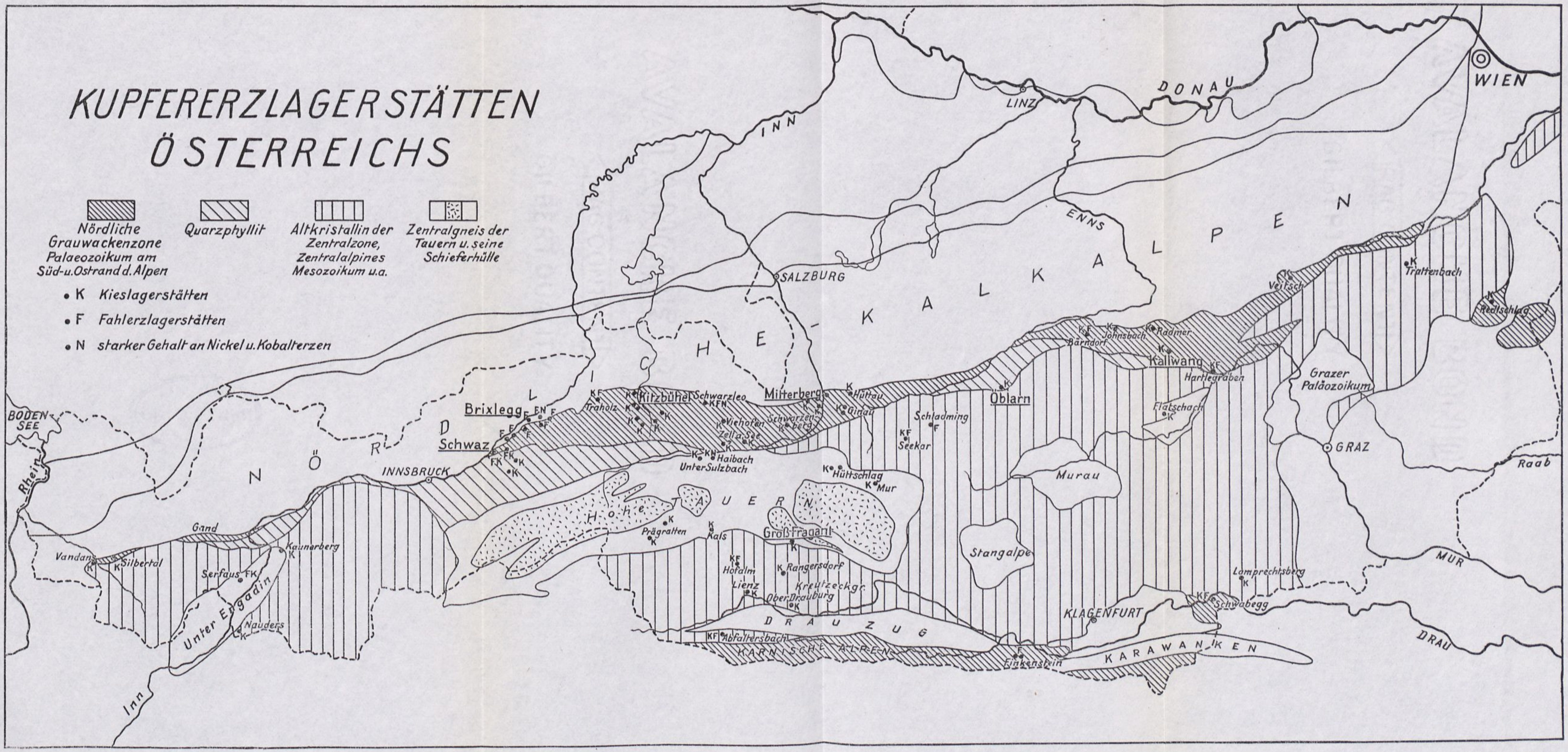
Aus der großen Zahl von Kupfererzbergbauen, welche auf der Karte verzeichnet sind, können hier wegen des eng begrenzten Druckraumes nur jene hervorgehoben werden, welche wirtschaftlich von größerer Bedeutung sind oder waren.

Unter den zahlreichen in Ankerit und Siderit umgewandelten Schollen altpaläozoischer Kalke des Radmertales enthalten einzelne bei Radmer an der Hasel große Nester und Linsen von Kupferkies und silberhaltigem Fahlerz, welche durch besonders hohen Kupfergehalt (bis zu 25 Prozent) ausgezeichnet waren und im 17. und 18. Jahrhundert einen ertragreichen Bergbau ermöglichten. Südlich benachbart liegt der Kiesbergbau Kallwang. Chloritschiefer (Metadiabase) und Phyllite, vermutlich karbonischen Alters, werden epigenetisch von lagerartig und als Imprägnation sich verbreitenden Pyrit, Magnetkies und Kupferkies durchsetzt. Der durchschnittliche Kupfergehalt der Erze ist 2.5 bis 3 Prozent. In den die Grauwackenzone im Süden begrenzenden Phylliten des Ennstales liegt die epigenetische Kieslagerstätte von Oeblarn, welche aus drei konkordanten Kieslagern (Schwefelkies und Kupferkies) von je einem Meter mittlerer Mächtigkeit und einem Durchschnittsgehalt von 1 bis 3 Prozent Kupfer besteht.

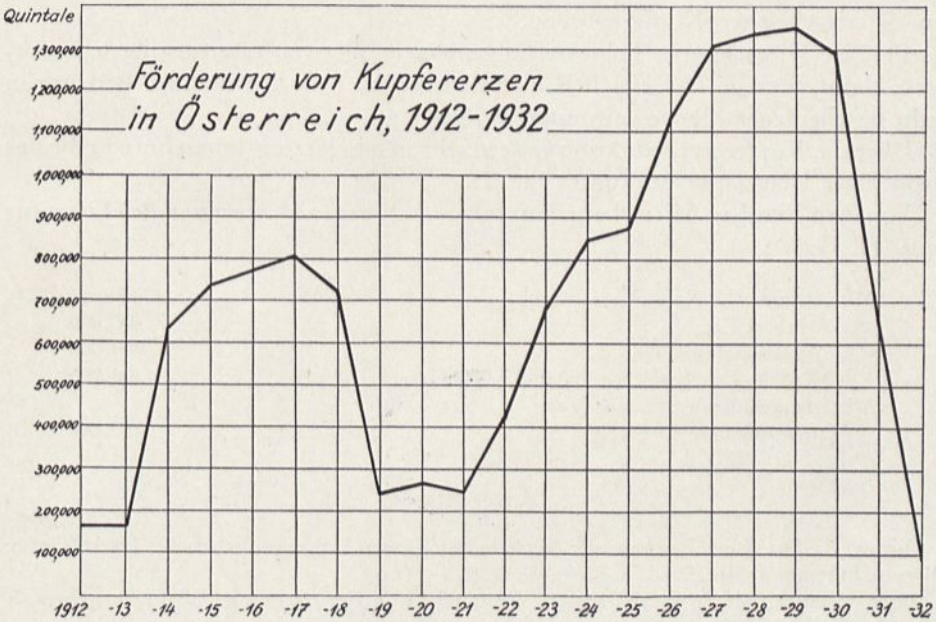
Die bedeutendste Kupfererzlagerstätte Österreichs ist Mitterberg (Salzburg). Sie lieferte 80 Prozent der Kupferproduktion der österreichisch-ungarischen Monarchie, und einen noch höheren Anteil im heutigen Österreich. In silurischen, serizitischen Grauwackenschiefern setzen der „Hauptgang" und seine Abspaltungen auf annähernd dem Streichen und der Transversalschieferung folgend. Er ist auf 6½ Kilometer im Streichen bekannt; die Mächtigkeit wechselt rasch und, beträgt im Mittel etwa 2½ Meter, die erschlossene Saigerteufe 700 Meter. Der durchschnittliche Kupfergehalt der Gangmasse ist 2.5 bis 4 Prozent. Die Gangarten sind Quarz, Ankerit und Siderit, seltener Dolomit und Kalzit; Haupterze sind Kupferkies und Schwefelkies. Mehrere kleinere Gänge gleichartiger Zusammensetzung liegen im Südrevier des Mitterberger Bergbaues (Brandergang, etc.).

Unter den zahlreichen kleineren Kupfererzvorkommen im Pinzgau sind jene im Schwarzleotal bemerkenswert, weil hier im Bergbau Nökkelberg neben Kupferkies die Nickel- und Kobalterze (Gersdorfit, Speiskobalt, etc.) wirtschaftlich maßgebend werden, während im Revier Schwarzleo neben Kupferkies noch Fahlerz hervortritt, und in der Gangart neben Eisenkarbonat und Quarz sich auch Anhydrit und Gips einstellen. Die Lagerstätten liegen im Silur-Devondolomit.

Das in früheren Jahrhunderten sehr ansehnliche Kupfererzrevier Kitzbühel umfasst fünf größere Baue neben zahlreichen kleinen, welche auf Gängen von Kupferkies, daneben auch Schwefelkies und Fahlerz umgingen. Die Gangzüge folgen oft dem Streichen der paläozoischen Schiefer, jene bei Jochberg Überschiebungsflächen. Die auf 1.8 Kilometer Länge und 800 Meter Teufe bergbaulich erfaßte Gangschar von Röhrerbühel war ausgezeichnet durch hohen Silbergehalt des Kupferkieses und förderte in den ersten 50 bis 60 Jahren des Abbaues jährlich durchschnittlich 2,100 Kilogram Silber und 420 Tonnen Kupfer. Das westlichste unter den größeren Kupfererzrevieren der Grauwackenzone ist jenes von Schwaz und Brixlegg. Hier ist Antimonfahlerz mit Gehalt von Silber und Quecksilber das führende Erz. Die Fahlerzgänge folgen in der Regel Querstörungen im silurischen Dolomit wie in der Randzone des angrenzenden Gneises, und führen in letzteren auch Kupferkies. Im Gneis treten auch reine Kiesgänge auf (Kupfer- und Schwefelkies).


KUPFERERZLAGERSTÄTTEN ÖSTERREICHS
Nördliche Grauwackenzone Palaeozoikum am Süd-u. Ostrand d. Alpen
Quarzphyllit
Altkristallin der Zentralzone, Zentralalpines Mesozoikum u.a.
Zentralgneis der Tauern u. seine Schieferhülle
• K Kieslagerstätten
• F Fahlerzlagerstätten
• N starker Gehalt an Nickel u. Kobalterzen
WIEN
DONAU
LINZ
INN
ENNS
SALZBURG
NÖRDLICHE KALKALPEN
BODEN-SEE
Rhein
INNSBRUCK
Brixlegg
Schwaz
Kitzbühel
Schwarzleo
Mitterberg
Hüttau
Öblarn
Trattenbach
Veitsch
Bärndorf
Johnsbach
Radmer
Kallwang
Hartlegraben
Flatschach
Grazer Paläozoikum
GRAZ
Raab
Murau
Stangalpe
MUR
Schladming
Seekar
Hüttschlag
Mur
Viehofen
Zell a. See
Haibach
Unter Sulzbach
Hohe Tauern
Großfragant
Prägratten
Kals
Hofalm
Lienz
Rangersdorf
Kreuzeckgr.
Ober Drauburg
DRAU ZUG
Abfaltersbach
KARNISCHE ALPEN
Finkenstein
KARAWANKEN
KLAGENFURT
Schwabegg
Lamprechtsberg
DRAU
Gand
Vandans
Silbertal
Kaunerberg
Serfaus
Unter Engadin
Nauders
Inn

Von den außerhalb der Grauwackenzone gelegenen Kupferbergbauen war der von Groß-Fragant einer der produktivsten. Im Südrand der Schieferhülle der Hohen Tauern liegen hier in Glimmer- und Chloritschiefer vier konkordante, fahlbandartige Imprägnationen mit Anreicherungen in Erzlinealen, bestehend aus Kupferkies und Schwefelkies in einer quarzigen Grundmasse mit Granat, Turmalin und Fuchsit (Kupfergehalt 2 bis 4 Prozent). Zahlreiche kleine Baue im Großarltal (Hüttschlag, Karteis, etc.) beuteten die kupferreichen Zementationserze von Kiesgängen in ähnlicher geologischer Lage aus. Wegen des weitverbreiteten Goldgehaltes zählen manche der zentralalpinen kupferhaltigen Kieslagerstätten zu den Goldbergbauen mit Kupfer als Nebenprodukt (zum Beispiele Waschgang bei Döllach, Schiedalpe bei Fusch).



Figur 67.

Gänge der spätigen Quarz-Kupferkiesformation mit Fahlerz und Kupferkies, wie jene der Grauwackenzone, wurden im Kupfer- und Silberbergbau Marienzeche in Schwabegg im unteren Drautal im paläozoischen Serizitschiefer abgebaut.

Teufenunterschiede: In Mitterberg, Oeblarn und zum Teil auch in Kallwang ist eine Abnahme des primären Kupfergehaltes mit zunehmender Tiefe festgestellt. An Stelle des Siderits nimmt in Mitterberg nach der Tiefe zu der Ankerit überhand. In Brixlegg haben die Fahlerzgänge in der Tiefe nur Baryt, höhere Teile auch Ankerit als Gangart. Eine Oxydationszone ist meistens nicht mehr erhalten, wogegen die Anreicherungen von Kupfer und Edelmetallen in der Zementationszone bei den alten Bauen oft ihre Blütezeit oder überhaupt den Bestand ermöglichten.

Der Kupferbergbau Österreichs reicht in die vorgeschichtliche Zeit zurück. Am Mitterberg wurde bereits in der Stein- und Bronzezeit in ausgedehntem Maße Kupfer gewonnen, desgleichen im Kitzbühler Revier. Nach jahrtausendlanger Uuterbrechung erfolgte dann im 15. und 16. Jahrhundert ein starker allgemeiner Aufschwung des ostalpinen Bergbaues, welcher auch die meisten der oben angeführten Reviere betraf, und sie teils im 16. teils im 17. Jahrhundert zur höchsten Blüte brachte.

Im 18. Jahrhundert sinkt infolge Erschöpfung der Lagerstätten, technischer Unvollkommenheit, Kriegszeiten und politischer Wirren, und im 19. Jahrhundert schließlich auch durch den Wettbewerb des Weltmarktes die Produktion und es kommen die meisten Baue zum Erliegen. Mitterberg wurde jedoch erst 1827 neu entdeckt und entwickelte sich dann rasch zu seiner beherrschenden Stellung im österreichischen Kupferbergbau.

1932 ist Mitterberg in Folge der allgemeinen Wirtschaftskrise stillgelegt worden, sodaß jetzt in Österreich Kupfererze nur noch in Schwaz und Brixlegg in sehr bescheidener Menge gewonnen werden.

Über die Kupfererzproduktion Österreichs in den letzten Jahrzehnten gibt das beigefügte Diagramm Auskunft (fig. 67).

Von dem Bergbau Mitterberg liegt folgende Vorratsschätzung in der Literatur vor (H. Beck):

Mitterberg (1925) Nordrevier:	Tonnen
Sichtbare Erze	500,000
Wahrscheinliche Erze	1,900,000
Mögliche Erze (zwischen 700 und 1,000 Meter Teufe)	2,300,000
Mitterberg Südrevier:	
Aufgeschloßene Erze	150,000

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Die Kupfererzlagerstätten im Königreich Bulgarien

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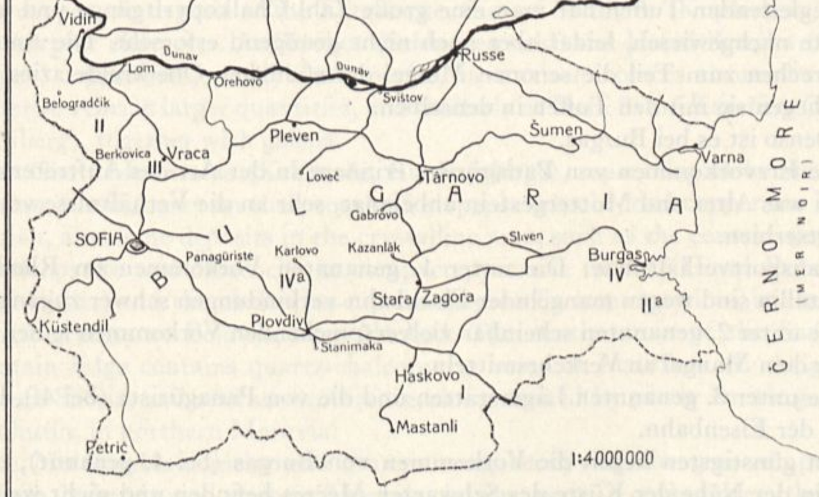
Die Kupfererzlagerstätten Bulgariens (fig. 68) sind noch ungenügend erforscht. Man unterscheidet vier Lagerstättentypen:

1. Gänge von Chalkopyrit mit Pyrit, Bleiglanz und Sphalerit im Rhodopen-Krystallin, hauptsächlich im unteren Ardatal.

2. Ein sehr bedeutender, 18 Kilometer langer, 0.1 bis 20 Meter und darüber mächtiger, Ost-Südost-West-Nordwest streichender Gang in den Silurschiefern, begleitet von Marmoren und durchbrochen von dioritischen Massen, im paläozoischen Kern des großen Berkovica-gewölbes. Er enthält Bleiglanz, Kupfererze und Siderit, an einigen Stellen auch Magnetit neben Skarn. In der römischen, byzantinischen und altbulgarischen Zeit, bis 1682, Gegenstand sehr reger Ausbeutung, aber jetzt wenig erforscht. Genesis: Metasomatose, begleitet von hydatogenen Vorgängen. Über die Erzmengen ist nichts bekannt.



Figur 68.—Die Kupfererzlagerstätten im Königreich Bulgarien.

2a. Bei Karharman südlich von Burgas hat man eine ähnliche Lagerstätte nachgewiesen: das Erz (Chalkopyrit) liegt am Kontakt von Diorit mit paläozoischem (?) Kalk, begleitet von Skarn. Durch einen 15 Meter tiefen Schacht sind 10,000 Tonnen Erz mit bis zu 4 Prozent Kupfer nachgewiesen worden.

3. Unregelmäßige, ziemlich bedeutende Nester im Muschelkalk im Vračanski Balkan, vermutlich ausgepreßt aus der Gesamtmasse der Kalke und in die

Hohlräume der Mulden- und Sattelbiegungen während der Faltung eingewandert. Nach den bisherigen Beobachtungen kann man an eine ursprünglich ziemlich gleichmäßige Verteilung des Erzes in bestimmten Kalkbänken denken. Die vererzten Zonen befinden sich im Muschelkalk der liegenden Hauptmulde, oder in den Stirnen der Falten zweiter Ordnung der großen, nach Norden stark überschobenen Berkovica-Falte. Erz: hauptsächlich Bornit, dann Tetraedrit, Chalcopyrit, begleitet von Bleiglanz. Die Grube Plakalnica im Vračanski Balkan hat bis jetzt 500,000 Tonnen Kupfererz geliefert mit durchschnittlich 4 Prozent Kupfer. Wahrscheinliche Vorräte sind ca. 150,000 Tonnen mit 2 bis 3 Prozent Kupfer.

4. Im Bezirk von Burgas wurden Erzgänge in zwei Revieren im Andesit studiert. Im Revier von Kara tepe, 12 Kilometer süd-westlich der Stadt, kennt man 10 Gänge, Nordost-Südwest streichend. Der längste ist 2 Kilometer lang und wurde mit bis zu 160 Meter tiefen Schächten untersucht. Im zweiten Revier (Rossenbair) süd-östlich der Stadt gelegen, kennt man 15 Gänge, welche man mit einigen 60 bis 70 Meter tiefen Schächten verfolgt hat. Es sind in beiden Revieren etwa 180,000 Tonnen Erz aufgeschlossen und 500,000 bis 600,000 Tonnen wahrscheinlich vorhanden, mit durchschnittlich 4½ Prozent Kupfer.

In den oberen Teilen dieser Lagerstätten findet man meistens Chalkosin mit Quarz, in der Tiefe jedoch Chalkopyrit mit Quarz.

4a. Im Bezirk von Panagürište, Kreis Plovdiv, in den Andesiten und in den sie begleitenden Tuffen hat man eine große Zahl Chalkopyritgänge und kleine Stöcke nachgewiesen, leider aber noch nicht genügend erforscht. Die Andesite durbrechen zum Teil die senonen Mergel der südlichen Oberkreidefazies, zum Teil liegen sie mit den Tuffen in denselben.

Ebenso ist es bei Burgas.

Die Erzvorkommen von Panagürište erinnern in der Art des Auftretens, vor allem was Alter und Muttergestein anbelangt, sehr an die Verhältnisse von Bor in Ostserbien.

Transportverhältnisse: Die unter 1. genannten Vorkommen im Rhodopen Krystallin sind wegen mangelnder Eisenbahn verbindungen schwer zugänglich.

Die unter 2. genannten scheinbar vielversprechenden Vorkommen leiden auch unter dem Mangel an Verkehrsmitteln.

Die unter 3. genannten Lagerstätten und die von Panagüriste (bei 4.), liegen nahe der Eisenbahn.

Am günstigsten liegen die Vorkommen von Burgas (bei 4. genannt), da sie sich in der Nähe der Küste des Schwarzen Meeres befinden und nicht weit von der Eisenbahnlinie Burgas-Sofia entfernt sind.

In Bulgarien wurden bis jetzt etwa 190,000 Tonnen Erz mit 4½ Prozent Kupfer nachgewiesen; ca. 500,000 Tonnen mit 4½ Prozent und 150,000 Tonnen mit 2 bis 3 Prozent Kupfer sind wahrscheinlich vorhanden. Die möglichen Vorräte sind noch gar nicht ziffermäßig zu erfassen.

The copper deposits of Czechoslovakia

By F. Slavík
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The Czechoslovak Republic is not rich in copper ore deposits of economic value; the great industrial demand for copper is supplied now exclusively by imports. In the past many copper ore deposits were mined in both the Sudetian and the Carpathian parts of Czechoslovakia, but generally they were of only local significance. Much of the copper ore worked now or formerly accompanies other ores—for example, siderite in the veins and deposits of Slovakia or tin ore in Bohemia—or is contained in deposits of iron pyrite.

The crystalline Bohemian massif contains in the west veins with chalcopyrite as the principal primary ore mineral at Mutěnín (Muttersdorf) and Tři Sekery (Dreihacken), in the Bohemian Forest. In the Erzgebirge, on the Saxon boundary, west of Jáchymov (Joachimstal), there is a stratiform pyritic deposit in phyllite at Kraslice (Grasslitz), where mining began in the 13th century, culminated in the 16th and 17th centuries, and lasted till the World War. The principal ore mass consists of pyrite with admixed pyrrhotite and chalcopyrite. The other copper ore deposit of the Erzgebirge, that of Měděnec (Kupferberg) is of metamorphic character. At Slavkov (Schlaggenwald) and Horní Krupka (Obergraupen) copper ores, mostly chalcopyrite, have at some places accumulated on cassiterite veins in larger quantities, and similarly at Hora Svaté Kateřiny (Katharinenberg), together with galena.

The Giant Mountains (Krkonoše, Riesengebirge), separating Bohemia from Prussian Silesia, carry on their southern slope, besides bedded copper ore in the Permian, also some deposits in the crystalline area, such as the contact deposits of chalcopyrite and chalcocite in compact pyroxene rock at Horní Roketnice (Oberrochlitz) and the chalcocite-cuprite-chrysocolla impregnations in the porphyritic granite at Běloves, near Náchod. The continuation of the Sudetian mountain ridge contains quartz-chalcopyrite veins at Ludvíkov (Ludwigstal), in Czech Silesia, and another occurrence, characterized by partly baritic gangue, at Bohutín, in northern Moravia.

The Moldanubian gneiss and granite area, occupying the greatest part of southern Bohemia and western Moravia, is very poor in copper ores; the only deposit of any economic significance is that of Borovec, near Bystřicenad Pernštýnem, in Moravia, where chalcopyrite accompanied by quartz and barite forms an irregular ore body in gneiss.

In Czechoslovakia, as in other countries (central Germany, Russia), the lower Permian formation or its transition to the Carboniferous contains in its sediments disseminated or concretionary copper ores at many places. At most localities only impregnations of secondary malachite and azurite are found (Kalná and other localities below the Giant Mountains; Chrást, near Český Brod). The primary sulphide ores occur in small quantities. At Verneřovice (Wernersdorf), near the east end of the Giant Mountains, concretions of prevalent chalcocite, with accessory bornite and pyrite, are more abundant and were mined in the past decade.

In the Carpathian part of Czechoslovakia almost all the copper-bearing deposits, except the small admixtures with silver-gold ores of the Štiavnica (Schemnitz) district, belong to the metalliferous series of central and eastern Slovakia, the greatest part of which consists of slightly metamorphosed sedimentary rocks believed to be of lower Carboniferous age. The main vein filling consists of siderite; the sulphide copper ores—chalcopyrite and tetrahedrite with a quartz gangue—represent a later mineralization ("vein rejuvenation"). The veins and metasomatic deposits of this type are mined for iron, the copper being an additional product—for example, at Kotrbach, where the tetrahedrite is mercuriferous; at Gelnica, Mníšek (Einsiedel), and Spišská Nová Ves. Generally the copper is more abundant in the eastern part of the metalliferous series. Certain deposits belonging to the same group are of somewhat different character. At Smolník (Schmölnitz) the main mass of the lenticular ore bodies consists of pyrite with ½ to 2 percent of copper and was mined at first for copper and later for the manufacture of sulphuric acid, copper being a byproduct won from the cementation waters. At Košická Belá, Nandráž, and Lubietová, the copper ores with quartz (at Lubietová penetrating a mica schist) occur as the principal or only vein filling. The deposits of Španá Dolina (Herrengrund), of world-wide reputation for their beautiful crystallized minerals (celestite, aragonite) and for the rare secondary basic sulphate herrengrundite, extend upward into the Permian formation; they were mined, principally in the 16th century, on a large scale and furnished the material to the famous ancient copper works at Banská Bystrica (Neusohl).

The official data on the production of copper ores in Czechoslovakia are the following:

	Metric tons		Metric tons		Metric tons
1919	1,918.5	1924	590.2	1929	55,564.0
1920	3,752.8	1925	3,606.0	1930	72,578.0
1921	13.1	1926	16,699.0	1931	53,487.0
1922	12.1	1927	44,459.0	1932	None
1923	171.7	1928	52,312.0	1933	None

Almost the entire total of these figures represents the output of the iron-copper ore deposits of Slovakia; Bohemia contributed only from Kraslice and Verneřovice in 1919 (138.5 tons) and from Verneřovice in 1920 (200 tons), 1923 (106.3 tons), and 1924 (418.4 tons).

Copper ore bodies of Finland

By Martti Saksela

Geological Survey of Finland, Helsinki

Outokumpu

Outokumpu, 48 kilometers west-northwest of Joensuu (see fig. 69), is the most important copper ore body of Finland. The ore occurs in a quartzite 500 meters thick, intercalated in the predominant mica schist of the region. The quartzite contains layers of dolomite, for the most part changed into diopside- or tremolite-skarn, and numerous conformable intrusions of serpentine. Pegmatite dikes also occur. (See fig. 70.)

The strike is southwest and the dip 25°–60° SE. The pitch of the axis is constantly 10°–15° SW. The sulphide ore has been formed in a brecciated zone and is drawn out along the pitch of the axis. It ends abruptly at both sides. The dimensions of the ore body, as determined by drilling, are at least 1,800 meters in length and 250 meters in depth, with an average thickness of 5 meters (1 to 15 meters). There is at least 8,000,000 tons of ore in sight. On an average, the ore contains 4 percent of copper, 27 percent of iron, 1 percent of zinc, 26 percent of sulphur, and 39 percent of silica, together with minute amounts of gold (1 gram per ton), silver, cobalt, and nickel.

Shrinkage stoping is being used. The vertical distance between the levels is 35 meters. Where the dip is less than 45°, the broken material is drawn down to the loading chutes with the aid of scrapers.

All ore is concentrated. In the first phase, after grinding to about 4 millimeters, shaking tables were used, yielding a concentrate that contained 4.05 percent of copper, 42.05 percent of sulphur, 10 percent of silica, and middling. The middling was ground to 0.15 millimeter and subjected to flotation. The flotation concentrate contained 18.40 percent of copper, 35.30 percent of sulphur, and 8.80 percent of silica, and the residual tailings 0.41 percent of copper, 17.70 percent of sulphur, and 60.9 percent of silica. Beginning in 1934 all ore has been concentrated by flotation, yielding copper concentrate with 24 percent of copper and sulphur concentrate with 46 percent of sulphur.

The body was located by Dr. O. Trüstedt, mining engineer in the service of the Geological Survey of Finland, by tracing glacial boulders to a place 45 kilometers from the boulder of ore first found. This method is time-honored in Finland, having been used in 1737 by Daniel Tilas when prospecting in the southwestern part of the country. The ore body belongs to the Finnish Government—half by right of discovery, half by purchase.

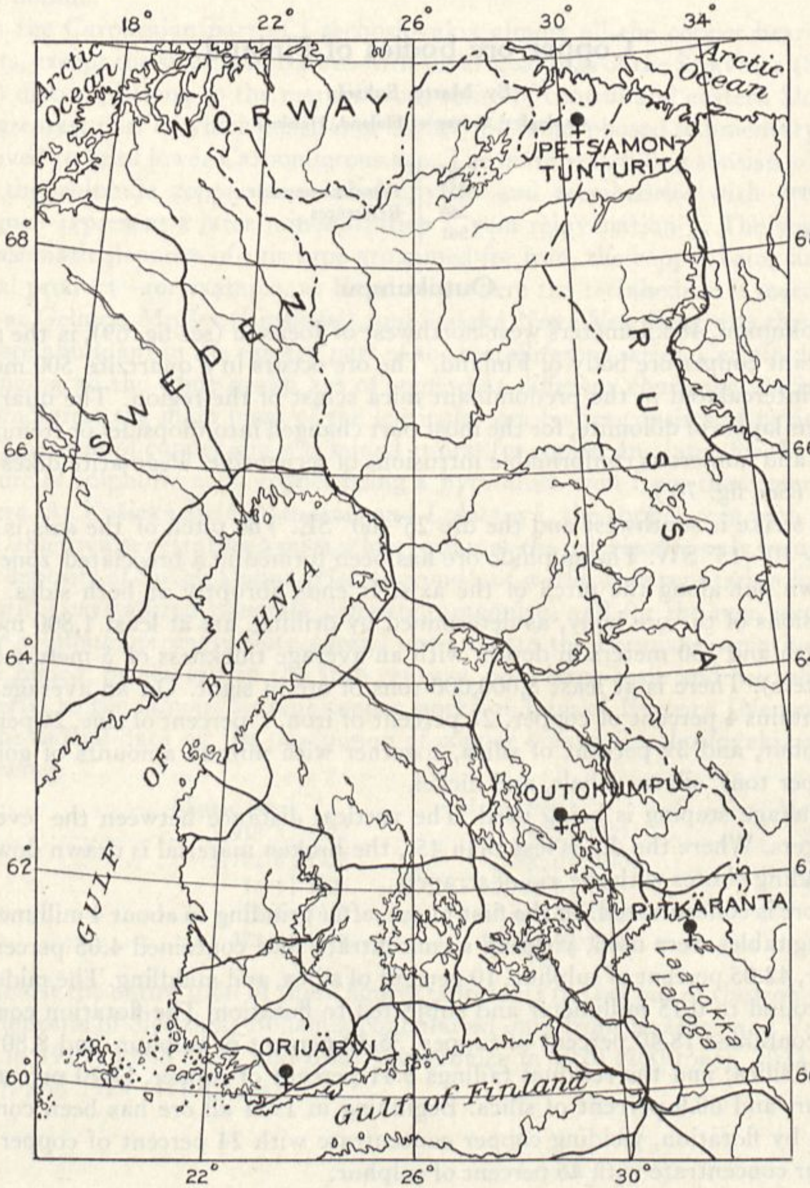

FIGURE 69.—Map showing copper ore bodies of Finland.

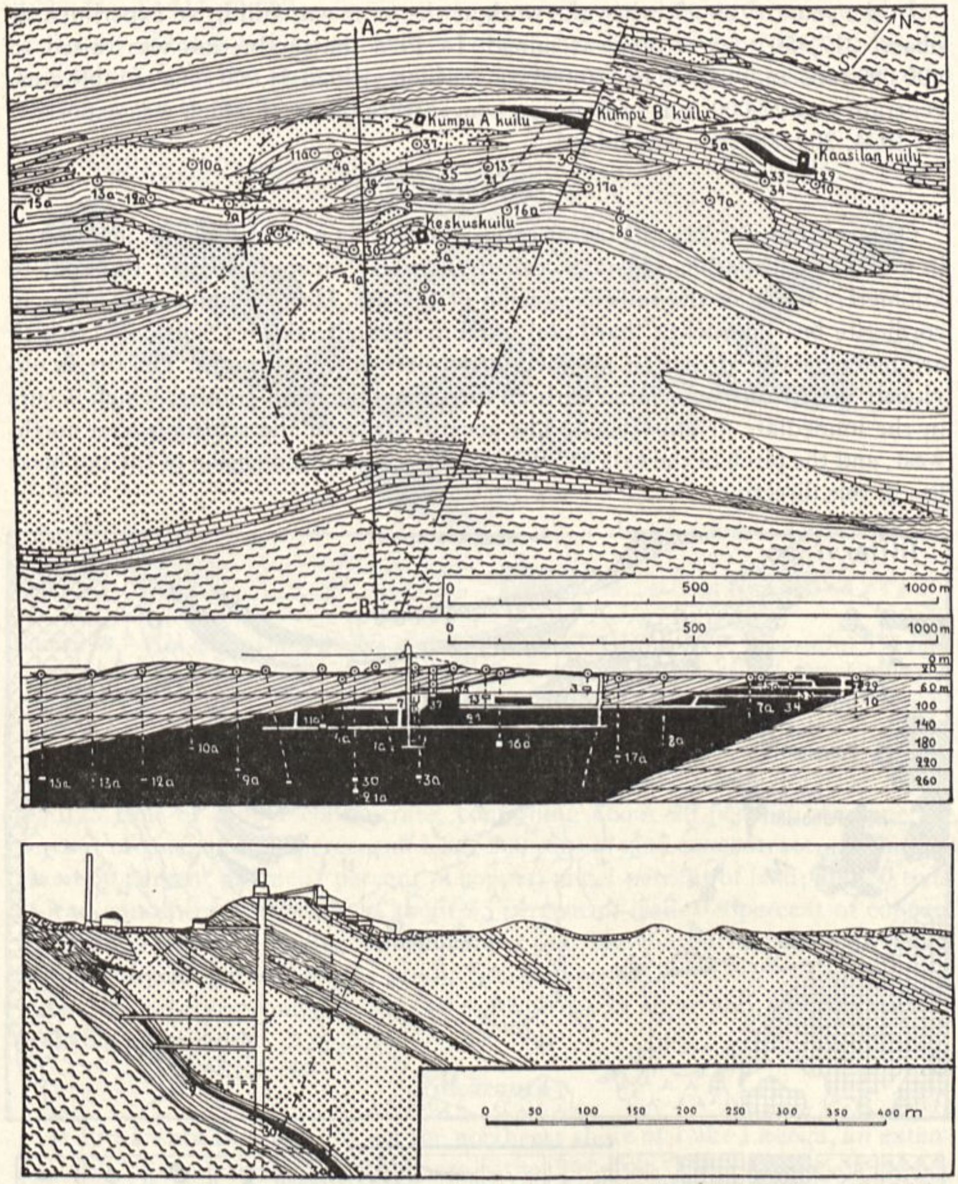

FIGURE 70.—The ore bodies of Outokumpu, Finland, according to Mäkinen, 1930. The upper part of the figure is a map of the mining field. The middle part is a longitudinal section along the line C–D in a vertical projection. The lowest part is a transverse section along the line A–B, showing also the central shaft, concentrating mill, and power plant. The points surrounded by a circle on the map and the longitudinal section indicate the position of drill holes at the surface, and the straight dotted lines indicate the drill holes. The diagonal dotted line on the map indicates a fault. White in the longitudinal section is stoped ore. 1, Railroads; 2, mica schist; 3, quartzite; 4, graphite schists; 5, skarn; 6, serpentine; 7, copper ore and shaft.

In the years 1913–27, when the work at the mine was still in an experimental phase, 217,350 tons of ore was mined. In 1928 the production was raised to 100,000 tons and in 1930 to 150,000 tons, which yielded 34,000 tons of table concentrate and 22,000 tons of flotation concentrate, most of which was exported. In 1934, 300,000 tons was mined.

Orijärvi

Orijärvi (figs. 71, 72), the oldest copper-producing field of Finland, in situated in a belt of feldspathic schists, so-called "leptites," in southwestern Finland, 14 kilometers north of the railway station of Fiskars. Here sulphide ores occur in cordierite-bearing rocks ("hard ore") and in tremolite skarn ("soft ore"), which are metasomatic alteration products of leptites and limestones. The ore is obviously genetically associated with an intrusive oligoclase granite, which occurs in the immediate neighborhood. The general strike of the schists is west northwest, and the pitch of the axis 45° WNW. The greatest dimension of the ore body lies in this direction.

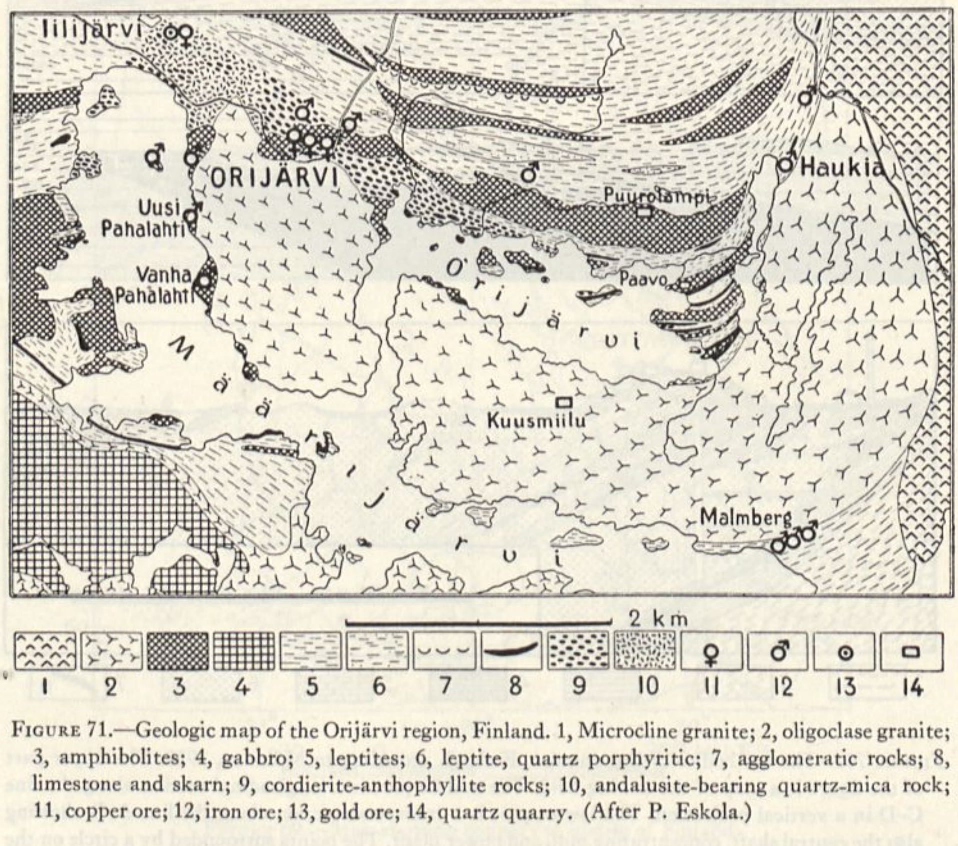

FIGURE 71.—Geologic map of the Orijärvi region, Finland. 1, Microcline granite; 2, oligoclase granite; 3, amphibolites; 4, gabbro; 5, leptites; 6, leptite, quartz porphyritic; 7, agglomeratic rocks; 8, limestone and skarn; 9, cordierite-anthophyllite rocks; 10, andalusite-bearing quartz-mica rock; 11, copper ore; 12, iron ore; 13, gold ore; 14, quartz quarry. (After P. Eskola.)

In the years 1757–1882 a total of 662,654 tons of copper-bearing rock was mined out, from which 133,525 tons of smelting ore was obtained, yielding 4,139 tons of copper, corresponding to a tenor of 0.62 percent. Mining began again in

1929. Until 1933, 50,000 tons of ore, on an average containing 5 percent of zinc, 2 percent of lead, and 1.3 percent of copper, has been mined. Most of this ore is obtained from the walls and roofs of the numerous old pits, which are to be broken down to the 60-meter level.

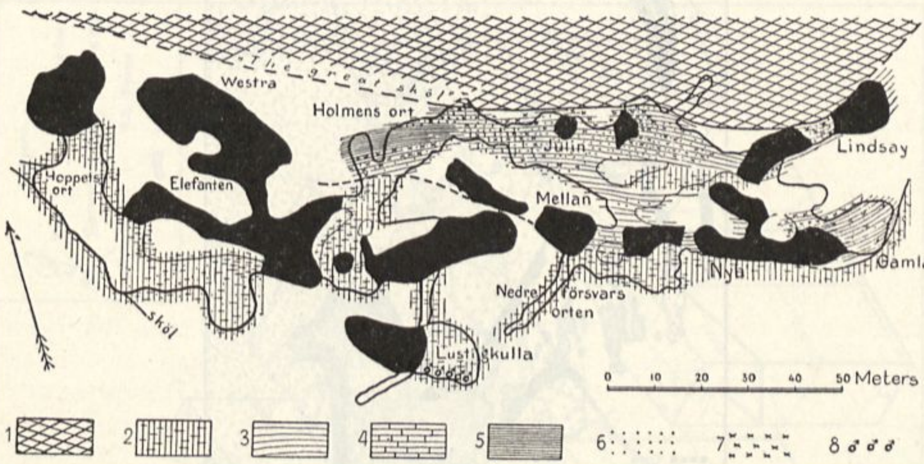

FIGURE 72.—Plan of the Orijärvi mine at the 30-meter level. (After A. F. Tigerstedt.) The rock boundaries are drawn mainly according to the observations of P. Eskola. 1, Amphibolite; 2, cordierite-anthophyllite rock; 3, tremolite-skarn; 4, limestone; 5, chlorite-biotite rock; 6, chalcopyrite; 7, sphalerite; 8, magnetite.

All the present output, 2,500 tons monthly, is concentrated by flotation, yielding 125 tons of copper concentrate, containing about 20 percent of copper, 9 percent of zinc, and 2.5 percent of lead; 200 tons of zinc concentrate, containing about 50 percent of zinc, 1 percent of copper, and 1 percent of lead; and 50 tons of lead concentrate, containing about 55 percent of lead, 0.9 percent of copper, 6 percent of zinc, and 1 kilogram of silver per ton. The concentrates contain about 3 grams of gold per ton. All the production is exported.

The ore reserves comprise 200,000 tons of ore in sight and 400,000 tons of probable ore.

Pitkäranta

At Pitkäranta (figs. 73, 74), on the northeast shore of Lake Ladoga, an extensive area of ore occurs. These ores are rather peculiar. They consist of copper and iron pyrites, sphalerite, galena, magnetite, and cassiterite, all interspersed in layers of dolomitic limestone on both sides of an amphibolitic schist that forms the lowest portion of the Ladogan series, in which elsewhere mica schists intercalated with layers of quartzite are the prevalent rocks. The substratum of this metamorphic sedimentary formation consists of a gneissose granite, and another Archean granite penetrates the schists. The youngest granite in the region is the so-called "Rapakivi granite," which forms a large area whose contacts cut all the older rocks. The contact surface dips below the adjacent older rocks in the west. The metamorphic action of the younger Archean granite has changed the

FIGURE 73.—Geologic map of the Pitkäranta mining field, Finland. Scale 1:250,000. (After O. Trüstedt.)

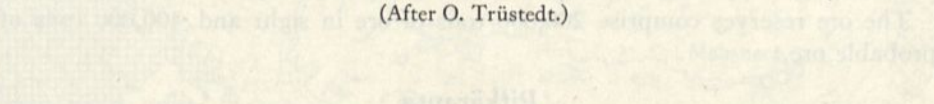

FIGURE 74.—Longitudinal section through the "old mining field" of Pitkäranta, according to O. Trüstedt. Workings on 1, copper ore; 2, iron ore; 3, tin ore; 4, zinc ore; 5, fault. Scale about 1:12,250.

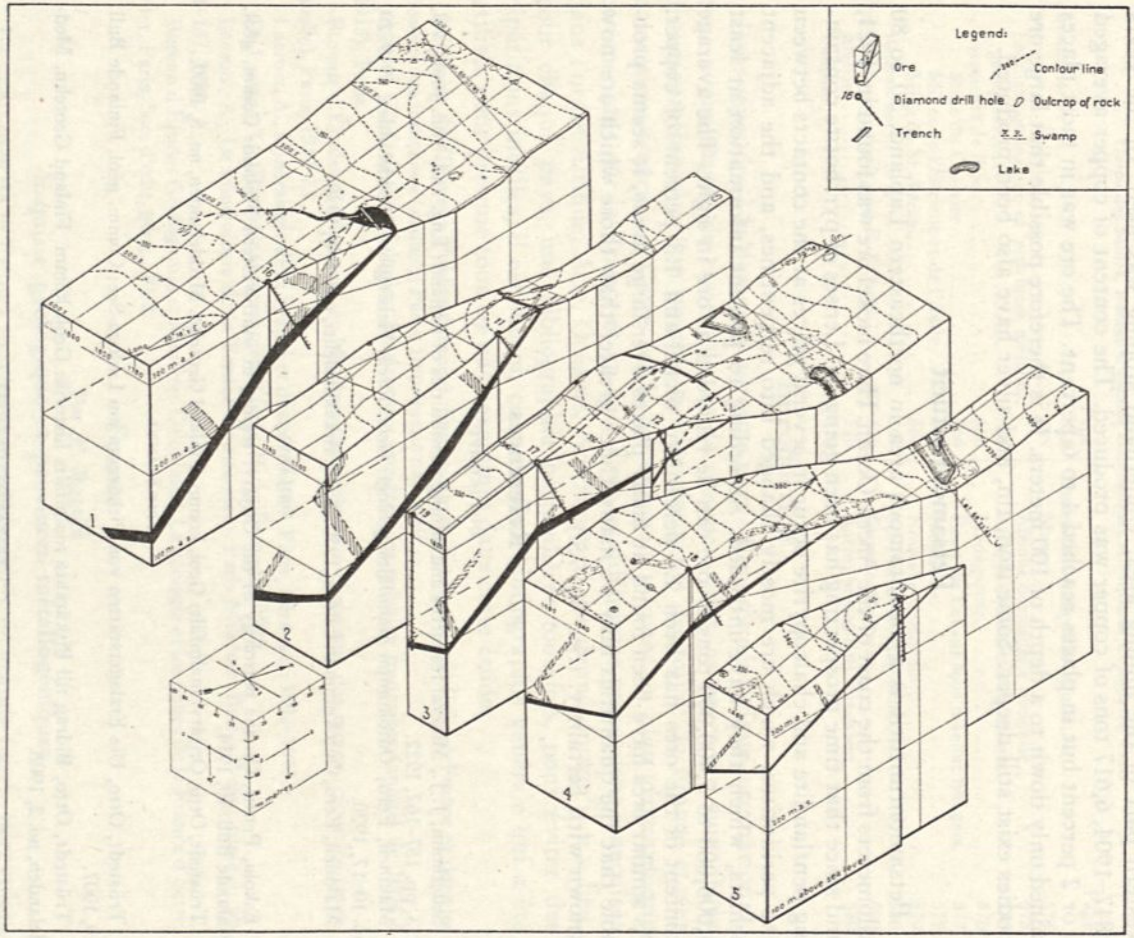

FIGURE 75.—Diagram of the nickel-copper ore body of Kaulatunturi, in Petsamo, Lapland.

limestones into skarn containing silicate minerals. The contact action of the Rapakivi granite has caused the formation of the ores and accompanying minerals.

The copper ores have been mined especially in a zone 2 kilometers long in the western part of the mining area. Underhand stoping was used. In the years 1847–1904, 6,617 tons of copper was produced. The content of copper averaged 1 or 2 percent but in places reached 4 to 6 percent. The ore was in most places mined only down to a depth of 100 meters. It is therefore possible that large ore bodies exist still deeper. Some iron, tin, and silver have also been produced.

Petsamontunturit

Petsamontunturit is a mountainous area in northeastern Lapland, 50 to 80 kilometers from the coast of the Arctic Ocean. Here nickel ore was found in 1921, and since that time prospecting has been going on. Lenses of pyrrhotite containing pentlandite and chalcopyrite occur in several places at the contacts between the peridotites, which are mostly changed into serpentines, and the adjacent schists, which they have intruded. According to present information at least 4,000,000 to 5,000,000 tons of ore can be regarded as ore in sight. The average content of the ores has been 1.7 percent of nickel and 1.3 percent of copper. As similar ores have been found at many places over large areas, it seems probable that the quantities may be many times greater than those which are now known with certainty. (See fig. 75.)

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Les gisements de cuivre de la France et des possessions françaises

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Introduction

Pour répondre à la demande adressée par le Congrès géologique international, nous avons essayé de rassembler et de résumer, dans les pages qui suivent, la documentation que l'on possède sur les gisements de cuivre de France et des possessions françaises. Cette étude est ordonnée suivant un plan géographique commençant par la France et en décrivant les différentes possessions françaises dans l'ordre Afrique, Asie, Océanie, Amérique. Il est donné, lorsqu'il y a lieu, pour chaque pays, une bibliographie particulière; toutefois, pour éviter des répétitions inutiles, il est fourni, ci-après, une bibliographie générale qui a été utilisée pour presque tous les pays examinés dans cette étude.

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France

Par E. Raguin

Esquisse géologique et provinces métallogéniques

La structure de la France présente un môle ancien, en grande partie hercynien, comprenant du Primaire normal ou métamorphique, des schistes cristallins d'âge indéterminé, des granites. Ce môle a été disjoint en plusieurs massifs séparés par des bassins déprimés, pendant les temps secondaires. Le plus important de ces massifs est nommé le "Plateau Central."

[1] Nous remercions très vivement M. Orcel de l'aide très précieuse qu'il a bien voulu nous apporter pour la préparation de cette étude.

En marge de la France hercynienne se sont formées, à l'époque tertiaire, les chaînes plissées des Alpes et des Pyrénées préparées par des mouvements tectoniques dès l'époque secondaire. Trois provinces métallogéniques principales se rattachent à ce développement tectonique, savoir:

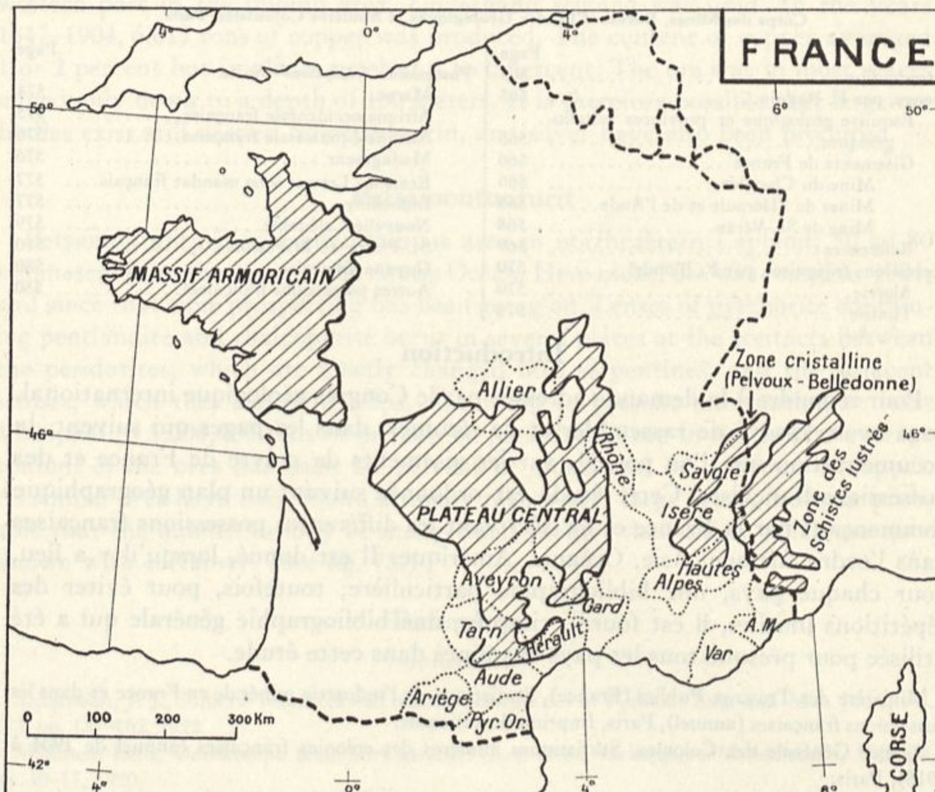

FIGURE 76.—Les provinces métallogéniques de la France.

Une province hercynienne liée à la fracturation de la fin de l'orogénie hercynienne. Le gisement du Charrier lui appartient.

Une province dans les vieux massifs, liée à leur fracturation au temps secondaire ou tertiaire par contre-coup des mouvements embryonnaires ou principaux des chaînes alpines. Les gisements de l'Hérault et de l'Aude s'y rapportent.

Une province alpine correspondant à la mise en place des roches éruptives basiques syntectoniques de la zone métamorphique de la chaîne alpine. Le gisement de St.-Véran en fait partie.

Gisements de France

Mine du Charrier

La mine du Charrier se trouve près du village de La Prugne (Allier) entre Vichy et Roanne, à 40 kilomètres de chacune de ces villes, au centre du massif granitique séparant les deux grandes dépressions oligocènes des vallées de l'Allier et de la Loire. En cette région, le massif granitique ancien supporte des lambeaux étendus de terrains dévoniens et carbonifères, très disloqués par les mouvements orogéniques hercyniens. Des intrusions ou des coulées de roches éruptives acides (microgranites, rhyolites) ont pénétré ces lambeaux de terrains primaires, simultanément ou postérieurement de peu à leur dépôt. Les zones minéralisées se trouvent dans des schistes chloriteux et quartzites primaires, très contournés et fracturés, modifiés par les venues éruptives.

D'après les renseignements communiqués par M. Armand, ingénieur au Corps des Mines, sur la disposition du gisement, les teneurs de métal et l'état actuel de la mine, il y a deux faisceaux de fractures principales—des failles N. 60° O. et des failles postérieures nord-sud. De la cassitérite imprègne les schistes et présente des enrichissements le long des premières fractures au contact de la roche éruptive, et au croisement des fractures. De l'érubescite et de la chalcopyrite constituent le principal minerai et se trouvent en amas, localisés généralement aussi en de tels croisements. D'autre part, les schistes sont riches en magnétite; et il existe, enfin, dans les failles nord-sud, des remplissages atteignant parfois 8 mètres de barytine avec galène argentifère.

Selon qu'il ressort de l'étude microscopique des minerais faite par M. Orcel, la cristallisation de la cassitérite a accompagné ou précédé de peu celle des sulfures, et ceux-ci, d'après leur mode d'association, sont primaires, et ne résultent pas de réactions de cémentation postérieures à la constitution du gisement. La stannine signalée autrefois n'a pas été retrouvée. Néanmoins, M. Orcel souligne la probabilité d'émanations sulfurées pour l'apport de l'étain comme des autres métaux. Le véhicule de l'étain serait, soit le sulfure d'étain, soit le sulfostannate de sodium, l'intervention des alcalis étant vérifiée par la présence de lépidomélane dans la gangue.

Dix amas de chalcopyrite et bornite ont été reconnus, ayant des dimensions de l'ordre de quelques dizaines de mètres en tous sens. L'un d'entre eux, plus allongé, a 100 mètres de longueur en projection horizontale. Plusieurs d'entre eux n'affleurent pas. Les explorations sérieuses n'ont pas dépassé une profondeur moyenne de 70 mètres, et ceci uniquement sur une seule zone linéaire de 400 mètres. Des possibilités importantes d'extension subsistent donc.

Le gisement, qui avait été l'objet d'une exploitation relativement considérable au siècle dernier, a été repris récemment et soumis à des études systématiques. Toutefois, la situation économique actuelle a remis l'usine en sommeil.

Dans les amas sulfurés, la teneur en cuivre atteint fréquemment 25 pour cent, la moyenne étant de 3.5 pour cent dans les parties exploitables. Il y a en même temps de l'argent, environ 6 kilogrammes par tonne de cuivre. La teneur en étain des schistes stannifères varie de 0.1 à 15 pour cent. En outre, les schistes sont riches en magnétite, avec une teneur en fer atteignant 40 pour cent, et comportant une moyenne de 25 pour cent.

Ces divers minerais sont d'habitude intimement mêlés. Le traitement prévu est une combinaison complexe de procédés gravimétriques de lavage, de flottations, d'une séparation magnétique et d'une fusion destinée à séparer étain et fer.

Mines de l'Hérault et de l'Aude

Il existe, d'une part, dans la Montagne-Noire au sud du Plateau Central, et, d'autre part, dans le massif primaire de Mouthoumet, qui lui fait face au bord des Pyrénées de l'autre côté de la dépression de l'Aude, de nombreux filons encaissés dans les terrains anciens, schistes siluriens plus ou moins métamorphiques et calcaires dévoniens. Ces filons comportent une minéralisation complexe avec pyrite, chalcopyrite, parfois cuivre gris, mispickel, galène.

Ils correspondent à des fractures de deux directions principales, voisines de est-ouest et nord-sud respectivement et formées probablement par contre-coup des plissements des Pyrénées. Nombreux et dispersés, irréguliers et à faibles teneurs, ils ne présentent que rarement une importance pratique.

Dans la Montagne-Noire le système filonien est-ouest a une minéralisation ferreuse, plombeuse ou cuivreuse, et le système nord-sud est arsenical, aurifère et argentifère avec un peu de cuivre.

Ainsi qu'il ressort des renseignements ci-dessous communiqués par M. Estival, ingénieur au Corps des Mines, les filons les plus notables sont ceux de Pujol et Salsigne, dans la Montagne-Noire, et ceux de Padern, dans le massif de Mouthoumet.

Gisement de Pujol.—A 20 kilomètres au nord de Carcassonne, plusieurs filons est-ouest dans les schistes siluriens présentent un remplissage quartzeux sur une épaisseur atteignant 6 mètres. De la chalcopyrite forme des veinules ou des rognons dans le quartz. Il a été extrait récemment et passé à la flottation 10,000 tonnes de minerai à une teneur moyenne de 0.6 pour cent de cuivre. Les filons, actuellement inexploités, sont incomplètement explorés.

Gisement de Salsigne.—Le gisement de Salsigne, situé dans la même région que le précédent, consiste en des filons nord-sud de mispickel auro-argentifère avec une teneur en cuivre de l'ordre de 0.3 pour cent. Le minerai est traité au "water-jacket" par fusion demi-pyritique et le cuivre est récupéré dans la matte. La production de cuivre a atteint 168 tonnes en 1931.

Gisement de Padern.—Le gisement de Padern se trouve dans le sud du massif primaire de Mouthoumet, à 15 kilomètres au nord-ouest de la localité d'Estagel, située elle-même sur la ligne de chemin de fer de Perpignan. Il comporte une série de filons est-ouest dans les calcaires dévoniens, avec cuivre gris, azurite et malachite, dans une gangue de barytine et quartz. La minéralisation est irrégulière, la teneur moyenne pouvant être de 1 pour cent en cuivre, avec 30 kilogrammes d'argent par tonne de cuivre. L'extraction en 1929 a été de 2,400 tonnes de minerai.

Mine de St.-Véran

La mine de St.-Véran se trouve à 6 kilomètres du village de St.-Véran, le plus haut village d'Europe, dans le département des Hautes-Alpes. Le gisement consiste en amas de bornite situés au voisinage de vastes lentilles de roches vertes, épaisses de plusieurs centaines de mètres et englobées dans les schistes lustrés. Comme il est bien connu, les schistes lustrés sont une formation secondaire et tertiaire métamorphisée peu avant les mouvements orogéniques alpins: on sait qu'ils contiennent des bancs puissants de roches éruptives (gabbros, dolérites, péridotites, etc.) transformées par le métamorphisme alpin en prasinites et serpentines et nommées "roches vertes."

Dans la région de la mine, les schistes ont une disposition isoclinale avec pendage vers l'ouest de 40°, et paraissent reployés en un anticlinal jalonné par un axe de cargneule triasique. De chaque côté de cet axe on retrouve le banc de roches vertes enclavé dans les schistes, ainsi que les zones métallifères associées.

Les roches vertes sont ici des serpentines et gabbros altérés avec développement de glaucophane. Les assises qui leur sont immédiatement subordonnées comportent une épaisseur d'environ 70 mètres de schistes silicifiés ou quartzites chloriteux amphiboliques (glaucophane et riébeckite), puis viennent les calcschistes séériciteux ordinaires de la série des schistres lustrés. Ces diverses roches ont été décrites par Pierre Termier, puis C. E. Wegmann.

Le minerai est principalement dans les quartzites, à une cinquantaine de mètres du bord de la serpentine, sous forme de veinules très irrégulières, ayant de 20 à 60 centimètres d'épaisseur, mais il peut aussi pénétrer dans la roche verte. Il consiste principalement en bornite. Un peu de chalcopyrite, de covelline, de cuivre natif s'y rencontrent rarement. Enfin de la magnétite et de l'oligiste s'observent aussi. Par l'examen microscopique, C. E. Wegmann a constaté que de la chalcosine s'associe intimement à la bornite, jusqu'à constituer parfois un tiers du mélange. Le glaucophane forme des inclusions dans les sulfures.

Le gisement a l'aspect d'une ségrégation périphérique en rapport avec la roche éruptive basique, mais il a dû aussi probablement enregistrer l'influence du métamorphisme général alpin. La silicification des schistes et leur enrichissement en alcalis (amphiboles sodiques) paraissent des conséquences de la venue des roches éruptives; et l'on peut penser avec C. E. Wegmann, que l'apport métallique provient de solutions résiduelles de sulfosels alcalins émanées du magma. D'après le même géologue le gisement ne comporte pas de cémentation superficielle de quelque importance.

Les zonules minéralisées se suivent assez discontinues sur environ 3 kilomètres le long de flanc ouest de l'anticlinal et sur une distance de moitié au flanc est. Plusieurs galeries ont été pratiquées à partir du versant, à des altitudes variant de 2,350 à 2,500 mètres.

Sans parler d'anciens travaux, d'après les renseignements communiqués par M. Charbonneaux, ingénieur au Corps des Mines, une exploitation suivie a eu lieu de 1924 à 1931, grâce à la découverte d'une colonne riche en bornite, possédant une section d'épaisseur maxima 8 mètres et de longueur 45 mètres avec 30 centimètres d'épaisseur moyenne de bornite pure. La hauteur reconnue de la colonne est de plus de 100 mètres. Le minerai titrant 7 pour cent de cuivre était traité à une laverie donnant des concentrés à 43 pour cent de cuivre. La production de ces concentrés à atteint près de 600 tonnes en 1930. La mine a été arrêtée en 1931.

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Possessions françaises

Par F. Blondel

Algérie

Si l'on met à part le gisement d'Ain-Sefra dans le Sud-oranais, qui est d'apparence sédimentaire, tous les gisements cuprifères d'Algérie (voir fig. 77) sont probablement d'âge tertiaire et font partie de venues complexes (cuivre, plomb, zinc) qui s'étendent de l'ouest à l'est, le long du littoral dans la chaîne montagneuse appelée "l'Atlas Tellien."

Quand on part de la frontière marocaine, à l'ouest, on a d'abord une zone plombo-cuprifère assez médiocre où le plomb est dominant.

Dans la région centrale de l'Algérie, la minéralisation semble suivre deux anticlinaux distincts—l'un sur la côte allant de Ténès à Alger; l'autre, qui est à peu près parallèle à une distance de 30 à 40 kilomètres, va d'Orléansville à Minerville.

La zone qui suit la côte commence autour du Cap Ténès par d'assez nombreux gisements filoniens de chalcopyrite et cuivre gris avec galène, pyrite de fer, sidérose et hématite. Dans cette zone, on signalera notamment la concession d'Oued Allelah, près de Montenotte, qui contient des filons de chalcopyrite, associée à la sidérose dans les marnes et grès du Miocène inférieur. Cette concession a été exploitée de 1850 à 1858 et a fourni 3,376 tonnes de produits marchands.

L'autre zone métallifère parallèle, mais située plus au sud, commence à l'ouest par le Djebel Temoulga, à 20 kilomètres au nord-est d'Orléansville. A cette bande correspond d'abord toute une série de gisements de fer jusqu'au moment où on arrive au gisement de Mouzaïa, situé à 10 kilomètres au nord-nord-ouest de Médéa. Ce gisement, qui a été un moment célèbre, comprend de nombreux filons irréguliers de cuivre gris argentifère avec sidérose et barytine dans des marnes crétacées. Ces filons sont accompagnés en surface par des dépôts d'hématite et passent en profondeur à la chalcopyrite. Ce gisement a été exploité de 1846 à 1860, puis de 1863 à 1876 et, enfin, de 1891 à 1897.

Cette zone se prolonge vers le sud-est et l'est par la concession de l'Oued-Merdja, située à 10 kilomètres au sud-sud-ouest de Blida, où l'on a exploité des filons de chalcopyrite associée à la sidérose dans des marnes crétacées. L'exploitation a eu lieu de 1852 à 1854 et de 1863 à 1877.

Dans la région de Bougie, département de Constantine, se trouve toute une série de gisements caractérisés notamment par la présence de cuivre gris. On signalera les suivants:

Le Djebel Téliouine, à 25 kilomètres au sud-sud-est de Bougie, montre des filons de cuivre gris à gangue de barytine dans les schistes néocomiens. Ce gisement a fourni une production insignifiante en 1886.

Le gisement de Tadergount montre également des filons de cuivre gris avec sidérose, encaissés dans les calcaires du Lias ou les schistes du Néocomien. Ce gisement a été exploité de 1880 à 1892, puis en 1899. Au total, de 1880 à 1912,

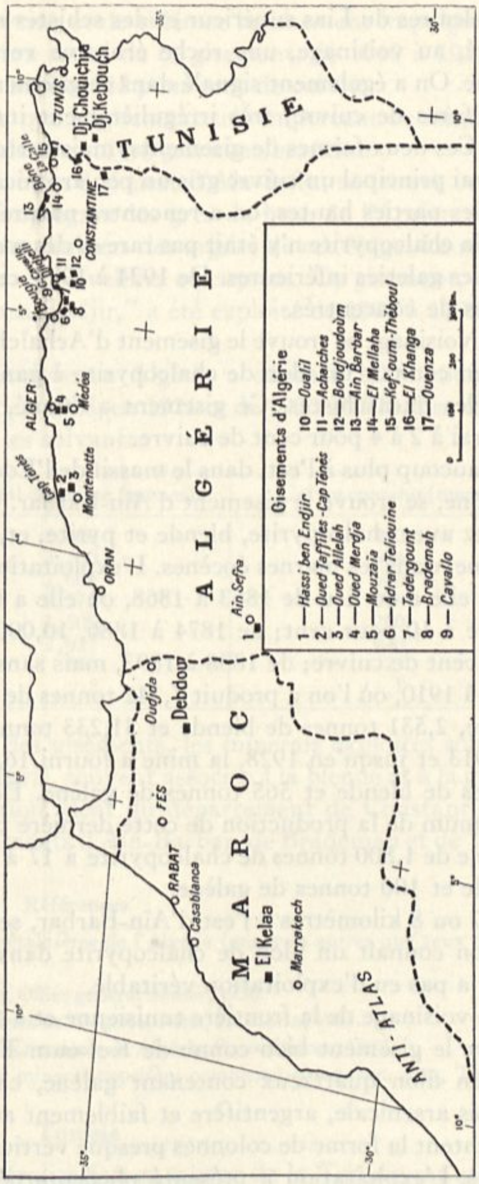

FIGURE 77. Les gisements de cuivre d'Algérie, du Maroc et de la Tunisie.

la production a été d'environ 3,500 tonnes de minerai marchand à 15 pour cent de cuivre et 400 grammes d'argent à la tonne. Il y a eu une reprise d'exploitation de 1927 à 1929, qui a fourni 850 tonnes de minerai en 1928.

Le gisement de Brademah est au voisinage du précédent. Il est constitué par une fracture dans les calcaires liasiques dont le remplissage est constitué par des boules de cuivre gris, emballées dans une gangue ferrugineuse. De 1910 à 1928, ce gisement a fourni environ 6,000 tonnes de minerai marchand à 18 pour cent de cuivre, le maximum ayant été atteint en 1926 avec 500 tonnes de minerai.

Dans le gisement pyriteux d'El Azouar (El Auzouar), à 30 kilomètres au sudest de Bougie, on a trouvé localement un minerai cuprifère complexe renfermant du cuivre gris argentifère associé à de la chalcostibite.

Un peu plus à l'est, se trouve la concession de Cavallo, près du Cap Cavallo, à 20 kilomètres à l'ouest-sud-ouest de Djidjelli. Ce gisement contient des filons ou lentilles de minerais complexes avec galène, blende, pyrite de fer, chalcopyrite, dans des roches éruptives probablement tertiaires. Il a été exploité vers 1878, époque à laquelle il a fourni 12,000 tonnes de minerai de cuivre à 10 à 15 pour cent, et en 1907, où il a donné quelques centaines de tonnes de chalcosine.

A 10 kilomètres au sud de ce gisement, se trouve le gisement de Oualil, qui contient des filons de chalcopyrite avec gangue d'ankérite et d'hématite, généralement sans cuivre gris, sauf pour quelques-uns d'entre eux. Ce gisement n'a pas été exploité.

Sensiblement plus à l'est se trouve le gisement de Boudjoudoun, situé à 9 kilomètres au sud d'El Milia. Ce gisement comporte notamment des imprégnations lenticulaires de cuivre gris à gangue de quartz et de barytine au contact des calcaires du Lias supérieur et des schistes néocomiens qui les recouvrent. On a noté, au voisinage, une roche éruptive verte qui parait être une dolérite à olivine. On a également signalé dans ce gisement une couche siliceuse, imprégnée de sulfures de cuivre, très irrégulièrement interstratifiée dans les calcaires du Lias. Ces deux formes de gisements, mais surtout la première, ont fourni comme minerai principal un cuivre gris un peu arsenical, contenant du plomb et du zinc; dans les parties hautes, on a rencontré naturellement l'azurite et la malachite; mais la chalcopyrite n'y était pas rare et des mouches de blende ont été observées dans les galeries inférieures. De 1924 à 1927, ce gisement a produit environ 1,500 tonnes de concentrés.

Au voisinage se trouve le gisement d'Achaïches, non loin du village de Catinat, où l'on connait un filon de chalcopyrite à gangue de quartz, barytine et calcite dans les micaschistes. Ce gisement a donné, de 1906 à 1908, 9,000 tonnes de minerai à 2 à 4 pour cent de cuivre.

Beaucoup plus à l'est, dans le massif de l'Edoug, à 20 kilomètres au nord-ouest de Bône, se trouve le gisement d'Aïn-Barbar. Ce gisement contient des filons de quartz avec chalcopyrite, blende et pyrite, et, plus accessoirement, galène, pyrrhotine, dans les marnes éocènes. L'exploitation de ce gisement a été très irrégulière; elle a eu lieu de 1863 à 1868, où elle a fourni 1,150 tonnes de minerai de cuivre à 10 pour cent; de 1874 à 1886, 10,000 tonnes environ de minerais à 10 pour cent de cuivre; de 1888 à 1893, mais sans fournir de minerais de cuivre; de 1901 à 1910, où l'on a produit 7,242 tonnes de chalcopyrite à 10 à 15 pour cent de cuivre, 2,531 tonnes de blende et 31,233 tonnes de mixtes cuivre-zinc. A partir de 1913 et jusqu'en 1928, la mine a fourni 16,827 tonnes de chalcopyrite, 7,184 tonnes de blende et 565 tonnes de galène. De 1921 à 1924, qui correspond au maximum de la production de cette dernière période, la moyenne annuelle a été voisine de 1,800 tonnes de chalcopyrite à 17 à 18 pour cent, de 1,200 tonnes de blende et 100 tonnes de galène.

A 7 ou 8 kilomètres à l'est d'Aïn-Barbar, se trouve le gisement d'El-Mellaha, où l'on connaît un filon de chalcopyrite dans une gangue quartzeuse, mais où il n'y a pas eu d'exploitation véritable.

Au voisinage de la frontière tunisienne et à 15 kilomètres à l'est de La Calle se trouve le gisement bien connu de Kef-oum-Théboul. Ce gisement est constitué par un filon quartzeux contenant galène, chalcopyrite et blende avec pyrite parfois arsenicale, argentifère et faiblement aurifère. Les parties riches du filon présentent la forme de colonnes presque verticales se rejoignant près des affleurements. L'exploitation a présenté plusieurs périodes d'activité: de 1849 à 1893, période pendant laquelle il a été extrait 285,000 tonnes de minerais marchands (galène, blende, chalcopyrite), dont on ne connait pas d'ailleurs la répartition en chacun des minerais; de 1899 à 1903, où l'on a extrait 5,777 tonnes de carbonate de plomb, 6,971 tonnes de chalcopyrite, 2,294 tonnes de blende, 23 tonnes de galène et 3,904 tonnes de mixtes blende-galène; enfin, de 1907 à 1914, où l'on a produit 429 tonnes d'oxydes de plomb, 13 tonnes de galène, 5,112 tonnes de mixtes blende-galène et 13,000 tonnes de minerais de cuivre, à 5 pour cent de cuivre. L'exploitation est arrêtée depuis cette date.

Plus au sud, mais toujours le long de la frontière tunisienne et dans la vallée de la Medjerda, se trouve le gisement d'El Khanga, où existent des lentilles d'allure filonienne formées de barytine et de sidérose intimement imprégnées de cuivre gris où de chalcopyrite. On a retiré de ce gisement, de 1910 à 1912, 458 tonnes de chalcopyrite contenant environ 25 pour cent de cuivre.

Plus au sud encore, on signalera que le gisement très important de minerai de fer de l'Ouenza contient des veinules de cuivre gris avec barytine.

Dans le Sud-oranais, à 13 kilomètres à l'ouest d'Aïn-Sefra, se trouve un gisement d'apparence sédimentaire, imprégant les grès de base de l'Aptien ou formant remplissage des fissures ou des feuillets des argiles de cet étage. Le minerai principal est de la chalcopyrite avec covelline et cuprite. Ce gisement, connu également sous le nom d'"Hassi ben Endjir," a été exploité de 1902 à 1905 et de 1910 à 1911.

La production de minerai de cuivre en Algérie a dépassé 1,000 tonnes de minerai de 1901 à 1908, en 1917 et en 1918, en 1921 et de 1923 à 1928. Les chiffres relatifs aux dernières années sont les suivants:

	Minerai de cuivre (tonnes)	Cuivre contenu (tonnes)
1923	2,600	460
1924	3,100	674
1925	2,600	500 (?)
1926	2,573	478
1927	1,500	260
1928	2,021	230
1929	550	25
1930	2	1

Ainsi qu'il résulte de l'analyse des gisements, les minerais exploités sont soit de la chalcopyrite, soit des cuivres gris, souvent associés à la blende et à la galène. La presque totalité de la production vient du département de Constantine et, dans les dernières années, des gisements d'Aïn-Barbar, de Brademah et de Tadergount.

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Tunisie

De même qu'en Algérie, la minéralisation en cuivre de la Tunisie est associée à la minéralisation en plomb et en zinc. Parmi les différents indices qui ont été signalés, on retiendra les deux suivants, tous deux situés dans la Tunisie septentrionale. (Voir fig. 77.)

Le Djebel Chouichia, dans la vallée de la Medjerda, à 20 kilomètres à l'ouest de Souk-el-Arba. Ce gisement est quelquefois cité sous le nom de "Djebel Hairech." Ce gisement est constitué par des lentilles minéralisées en cuivre gris antimonieux et arsenical avec produits oxydés vers la surface. Le gîte a été exploité de 1903 à 1909 et a fourni pendant ces 7 années 4,412 tonnes de mattes à 40 pour cent de cuivre ou de speiss à 47 pour cent.

Le Djebel Kebouch est situé un peu plus au sud, dans le voisinage du Kef. Il contient surtout du plomb et du zinc, mais a fourni accessoirement une petite quantité de cuivre de 1923 à 1927. Le gîte est constitué par un dôme elliptique de calcaire sénonien coupé suivant son grand axe par un affleurement triasique au voisinage du quel se trouvent des sulfures complexes. La production de minerai de cuivre, de 1923 à 1927, a été la suivante, en tonnes: 1923, 400; 1924, 300; 1925, 6; 1927, 80.

Depuis 1913 la seule production de minerai de cuivre en Tunisie a été celle du Djebel Kebouch signalée plus haut.

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Maroc

L'exploration minière du Maroc n'est pas aussi avancée que celle de l'Algérie et de la Tunisie, et il est plus difficile de donner un exposé systématique des indices de cuivre reconnus dans ce pays. On citera les régions suivantes (fig. 77):

Debdou, à 130 kilomètres au sud-ouest d'Oudjda, dans le Maroc nord-oriental. Ce gisement est constitué par des amas de ségrégation, interstratifié dans des schistes et probablement en relation avec un massif granitique. La nature des minerais de cuivre de ce gisement n'est pas précisée; ils se trouvent dans une gangue de silicate.

El Kelaa, à 70 kilomètres au nord-est de Marrakech (Maroc sudoccidental). Dans cette région, ainsi d'ailleurs que dans d'autres régions voisines, on a signalé des filons de chalcopyrite.

On connaît la chalcopyrite associée à la blende au voisinage du gisement de grenatite à molybdénite d'Azegour, à 80 kilomètres environ au sud-ouest de Marrakech.

A la base de la série marno-calcaire cambrienne de l'Anti-Atlas se trouve une zone où de minces bancs calcaires alternent avec des schistes et des grès. Ces grès seraient plus ou moins minéralisés en cuivre sous une forme qui n'est d'ailleurs pas précisée.

On rappellera le gisement remarquable de chalcostibite signalé par Ungemach dans la région de Rar-el-Anz, dans la vallée de l'Oued Cherrat à l'est de Casablanca.

La Statistique de l'industrie minérale (Ministère des travaux publics de France) ne cite de production de minerai de cuivre au Maroc qu'en 1929, où l'extraction aurait été de 2,070 tonnes de minerai contenant 75 tonnes de métal.

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Afrique occidentale française

Le cuivre a été signalé en plusieurs points de l'Afrique occidentale française (fig. 78) et notamment dans les régions suivantes:

Au Soudan, dans les deux gisements de Seï (à 3 kilomètres à l'ouest de Sirakoro, région de Nioro) et de Lambatara (entre Kayes et Nioro). Dans ces deux points, on a trouvé de la malachite dans des grès paléozoïques.

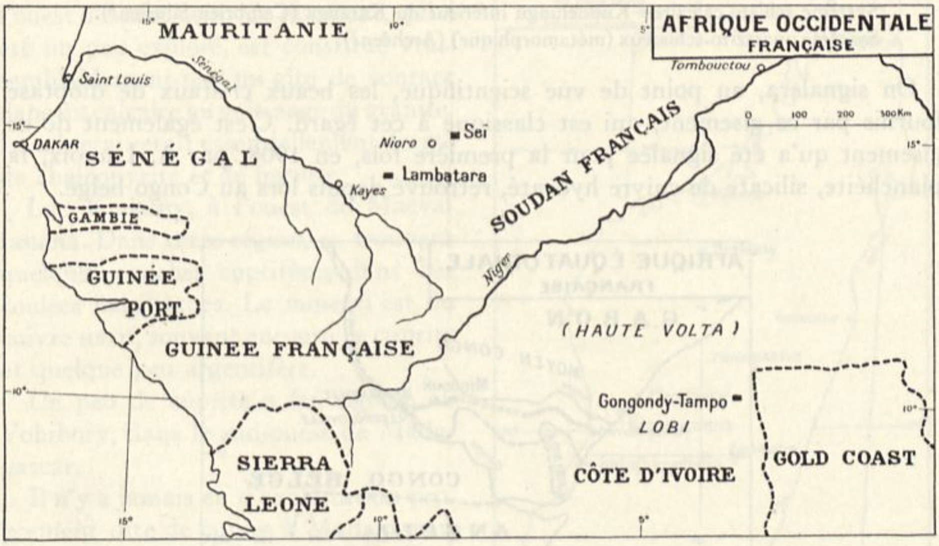

FIGURE 78.—Les gisements de cuivre en Afrique occidentale française.

Dans le Lobi, situé au nord de la Côte d'Ivoire (ce territoire faisait partie de la colonie de la Haute Volta, division administrative qui a été supprimée il y a peu de temps), à Gongondy-Tampo. Dans ce dernier point, on a trouvé de la chalcosine, probablement dans des schistes plus ou moins métamorphiques. Les recherches ont fourni la production suivante, en tonnes:

	Minerai	Cuivre contenu
1930	600	135
1931	900	200

Un échantillon de quartz avec veine de chrysocole et mouches de chalcosine a été rapporté récemment du Tibesti; le gisement en place n'a pu être précisé.

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Afrique équatoriale française

La seule région cuprifère connue en Afrique équatoriale française est celle du Niari, dans la colonie du Moyen Congo (fig. 79). D'après les renseignements publiés, la minéralisation serait constituée par de la chalcosine avec des produits divers d'oxydation. Cette chalcosine se rencontrerait au contact du système schisto-calcaire et du système schisto-gréseux. On sait que les géologues du Bas-Congo ont admis les grandes subdivisions stratigraphiques suivantes, de haut en bas:

Grès Batéké-Karroo? (Trias ou plus récent?).
Système schisto-gréseux—Kundelungu supérieur du Katanga (Dévonien?).
Système schisto-calcaire—Kundelungu inférieur du Katanga (Cambrien-Silurien?).
Système quartzito-schisteux (métamorphique) (Archéen?).

On signalera, au point de vue scientifique, les beaux cristaux de dioptase fournis par ce gisement, qui est classique à cet égard. C'est également de ce gisement qu'a été signalée pour la première fois, en 1908, par A. Lacroix, la planchéite, silicate de cuivre hydraté, retrouvé depuis lors au Congo belge.

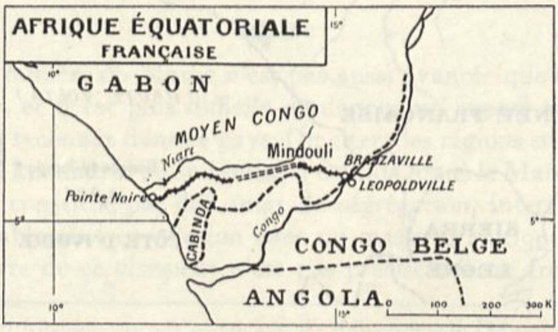

FIGURE 79.—La région cuprifère en Afrique équatoriale française.

Un début d'exploitation (à titre de recherches) a lieu à Mindouli, 120 kilomètres à l'ouest de Brazzaville. Les chiffres de production en tonnes des dernières années seraient les suivants:

	Minerai	Cuivre contenu
1928	3,000	380 (?)
1929	3,060	180
1930	9,700	580
1931	1,300	80

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Madagascar

Les divers indices de cuivre qui ont été signalés à Madagascar se trouvent dans les régions suivantes (fig. 80):

Androta, au sud-ouest de Vohemar (au nord de la côte nord-est). En ce point, on peut noter des veines quartzeuses intercalées dans les chloritoschistes et contenant de la bornite.

Kiranomena, au sud-est de Miandrivazo, sur la limite des terrains cristallins et sédimentaires, près de la Tsiribihina. En ce point se trouvent des fahlbandes dans un gneiss pyroxénique et amphibolique avec imprégnation de bornite et de chalcopyrite.

Ambatofangehana, à 30 kilomètres à l'ouest d'Ambositra. Ce gisement, qui a été un peu exploré, est constitué vraisemblablement par un gîte de contact dans un calcaire au voisinage du granite. Le minerai serait essentiellement formé de chalcopyrite et de bornite.

Lac Kinkony, à l'ouest de Maevatanana. Dans cette région, se trouvent quelques couches cuprifères dans des coulées basaltiques. Le minerai est du cuivre natif, souvent entouré de cuprite et quelque peu argentifère.

Un peu de cuprite a été signalé au Vohibory, dans le sud-ouest de Madagascar.

Il n'y a jamais eu d'exploitation proprement dite de cuivre à Madagascar, mais les recherches, notamment à Ambatofangehana, ont donné la production suivante: 1918, 18 tonnes de minerai; 1921, 4 tonnes; 1925, 2 tonnes.

FIGURE 80.—Les régions cuprifères du Madagascar.

Référence

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États du Levant sous mandat français

Dans les états du Levant sous mandat français le cuivre a été signalé dans les points suivants (fig. 81):

Ak-Chaï (environs d'Alexandrette), malachite dans des calcaires métamorphiques.

Kizil Dagh, malachite dans des serpentines.

Dans la zone côtière, au sud du Tachta-Tchaï, chalcopyrite.

Sur les pentes méridionales du Djebel Akra, chalcopyrite.

Ces divers indices n'ont pas donné lieu à exploitation.

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Indochine

Tonkin.—On a signalé le cuivre en plusieurs points du Tonkin (fig. 82), qui peuvent se grouper de la manière suivante:

Dans le nord et dans le nord-est, le minerai de cuivre serait associé à une minéralisation plomb-zinc; ce serait notamment le cas dans la montagne du Mau-son, près de Lang-son, d'où l'on aurait extrait, en 1911,12 tonnes de cuivre gris et, de même, dans la région d'An-chau, au sud de Lang-son, d'où l'on aurait retiré 5 tonnes de cuivre gris en 1910.

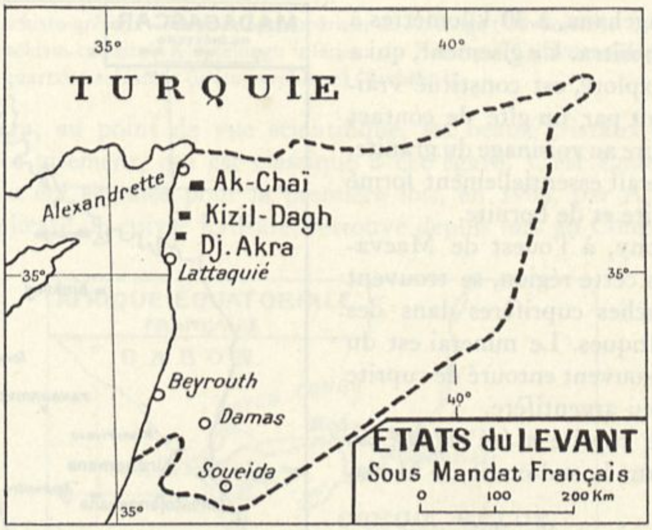

FIGURE 81.—Les régions cuprifères des états du Levant sous mandat français.

Dans le sud-ouest du Tonkin, et notamment dans le bassin de la Rivière Noire, on a signalé en divers points des indices de cuivre associés à des roches vertes (andésites et porphyrites) que l'on considère généralement comme triasiques et contemporaines des principaux mouvements tectoniques du Tonkin. Le point le plus important est le gisement de Van-sai, à 30 kilomètres en amont de Van-yen. A Van-sai, le minerai se présente sous forme de veines quartzeuses avec bornite ou chalcosine disséminées dans la roche verte. Il y a eu sur ce gisement, de 1910 à 1914, un début d'exploitation qui a fourni environ 3,500 tonnes de minerai.

Un peu plus en aval, à quelques kilomètres au sud de Van-yen, on connait des indices de cuivre sous la forme de veines de chalcopyrite et de bornite, parfois même avec cuivre natif, dans des roches vertes plus ou moins laminées.

On a fait également quelques travaux à Da-chong, aux environs de Sontay, et au col de Kem, dans le massif du Mont Ba-vi, non loin de Da-chong, où l'on a trouvé de la chalcopyrite, de la bornite et du cuivre natif dans des roches vertes.

On indiquera également que du cuivre natif a été signalé de Ta-lung, dans la région de Cao-bang (nord-est du Tonkin). La chalcosine a été signalée de Lang-nhon, dans la région de Yen-bay, avec chalcopyrite et malachite, et du Nui Tong-phai, dans la région de Ha-giang, avec chalcopyrite et bornite.

Les gisements d'étain du Pia-ouac (nord du Tonkin) contiennent un peu de chalcopyrite avec pyrrhotine, stannine et blende.

Annam.—On a signalé, à Cam-lo, dans la province de Quang-tri, de la chalcopyrite, de l'érubescite, de la malachite et du cuivre natif. A Duc-bo, dans la province de Quang-nam, on a reconnu de la pyrite cuivreuse avec blende et bornite.

Laos.—Dans le Haut-Laos, on a également étudié des indices de cuivre dans la région de Pou Tong, à environ 100 kilomètres au nord de Luang-Prabang. On ne possède pas de renseignements précis sur ce gisement.

Dans la région d'Attopeu, le cuivre a été signalé, sous forme de malachite, au confluent de l'Houei Vih et de la Sé-Khong. Quelques indices de cuivre ont été trouvés dans le Cammon (Muong Nhommarat).

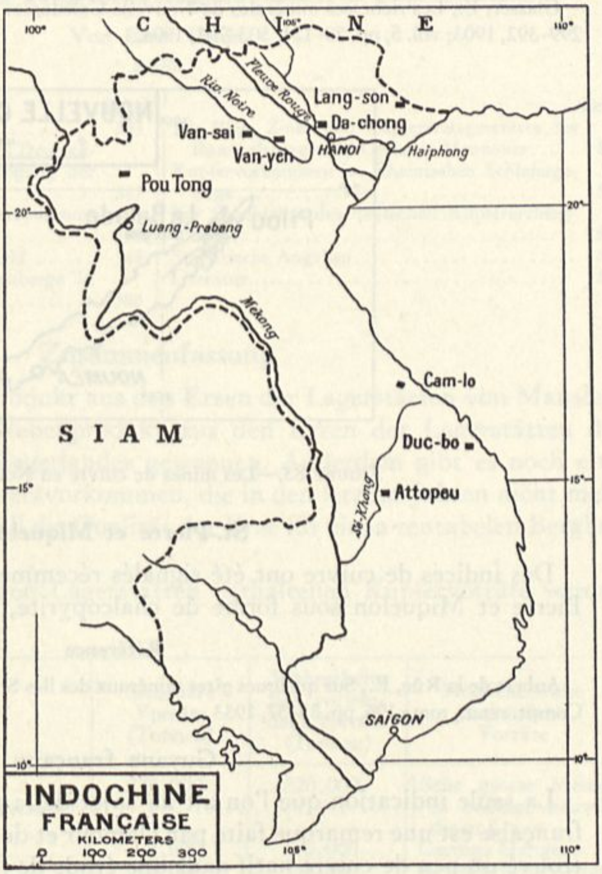

FIGURE 82.—Les gisements de cuivre de l'Indochine française.

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Nouvelle-Calédonie

Les indices de cuivre en Nouvelle-Calédonie (fig. 83) se trouvent dans le nord de la colonie. Les deux principaux ont donné lieu aux exploitations des mines de La Balade, près d'Ouégoa, et de Pilou, à peu de distance de la précédente, sur la rive gauche du Diahot. Ces gisements sont constitués par des filons quartzeux, parfois avec l'apparence de filons-couches, et dont le minerai est constitué par de la chalcopyrite, associée à la chalcosine, la covelline et la pyrite. Ces filons se trouvent dans des micaschistes ou dans les schistes anciens qui leur ont superposés.

L'exploitation a permis, entre 1873 et 1902, un exportation d'environ 50,000 tonnes de minerai d'une teneur moyenne de 10 à 15 pour cent, et de 1,000 tonnes de mattes notablement plus riches. Dans les années 1928 et 1929 une tentative de reprise a donné 1,000 tonnes de minerai contenant 50 tonnes de cuivre.

Reférénce

Glasser, E., Les richesses minérales de Nouvelle-Calédonie: Annales des mines, sér. 10, vol. 4, pp. 299–392, 1903; vol. 5, pp. 29–154, 503–701, 1904.

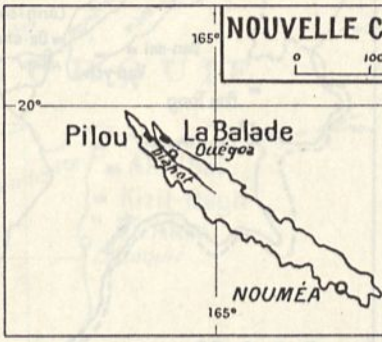


FIGURE 83.—Les mines de cuivre en Nouvelle-Calédonie.

St.-Pierre et Miquelon

Des indices de cuivre ont été signalés récemment en différents points de St.-Pierre et Miquelon sous forme de chalcopyrite, cuprite, malachite et azurite.

Référence

Aubert de la Rüe, E., Sur quelques gîtes minéraux des îles St.-Pierre et Miquelon: Acad. sci. Paris Compt. rend., tome 196, pp. 55–57, 1933.

Guyane française

La seule indication que l'on ait au sujet de la présence du cuivre en Guyane française est une remarque faite par Damour et de Rivot, selon laquelle on aurait trouvé un peu de cuivre natif dans une étude de fonds de batée pour recherches aurifères dans la région de la crique Hamelin, près de l'Aïcoupaï. Le cuivre était associé alors au platine et à l'argent natif.

Autres possessions françaises

Dans les autres possessions françaises, le Togo, le Cameroun, la Côte des Somalis, la Réunion, les Établissements français de l'Inde, l'Océanie française, la Martinique et la Guadeloupe, il n'a pas été signalé d'indices de cuivre, du moins à notre connaissance.

Die Vorräte der Kupfererzlagerstätten Deutschlands

Von Ernst Fulda

Berlin

Zusammenfassung

Kupfer wird als Hauptprodukt aus den Erzen der Lagerstätten von Mansfeld und Stadtberge und als Nebenprodukt aus den Erzen der Lagerstätten des Rammelsberges und des Siegerlandes gewonnen. Außerdem gibt es noch eine große Zahl weiterer Kupfererzvorkommen, die in den letzten Jahren nicht mehr produktiv gewesen sind, weil die Qualität der Erze für einen rentabelen Bergbau nicht ausreichte.

Die in den abbauwürdigen Lagerstätten enthaltenen Kupfervorräte werden folgendermaßen geschätzt:

	Sichtbare Vorräte (Tonnen)	Wahrscheinlich vorhandene Vorräte (Tonnen)	Möglicherweise vorhandene Vorräte
Mansfeld	270,000	320,000	Sehr grosse Mengen in bedingt bauwürdigen Erzen.
Sonstige Vorkommen von Kupferschiefer und Kupferletten	....	....	
Stadtberge	4,000	6,000	Geringe Mengen.
Rammelsberg	63,000	35,000	BeträchtlicheMengen.
Spateisensteingänge des Siegerlandes	1,000	6,000	Geringe Mengen.
Sonstige Kupfervorkommen	....	....	Beträchtliche Mengen.
	338,000	367,000	

Daraus ergibt sich, daß genügende Vorräte für die Dauer von etwa 20 Jahren bei der Fortsetzung des Kupfererzbergbaues im bisherigen Umfang auf allen Lagerstätten vorhanden sein werden. Darüber hinaus gibt es noch beträchtliche Vorräte, deren Gewinnung nur bei ganz besonders hohen Kupferpreisen in Frage kommen kann. Sie bilden eine Reserve für den Fall, daß einmal in der ganzen Welt die jetzt als bauwürdig erscheinenden Erze erschöpft sein sollten.

Kurze Beschreibung der Geologie von Deutschland mit besonderer Berücksichtigung der Erzgebiete

Nordöstlich der Linie Hannover-Magdeburg-Breslau liegt das norddeutsche Flachland, das überwiegend diluviale Ablagerungen zeigt, die alle älteren Bildungen fast vollständig verhüllen. In diesem Gebiet, das etwa die Hälfte von Deutschland ausmacht, sind bis jetzt keine Erzlagerstätten entdeckt worden.

Südwestlich von der genannten Linie liegt das Gebirgsland, das zum kleineren Teil aus kristallinen und paläozoischen Gebirgen, zum größeren Teil aus mesozoischen Hügellandschaften besteht.

Figur 84.

Im Mesozoikum kommen nur wenige Erzlagerstätten vor. Von wirtschaftlicher Bedeutung sind eine Blei-Zinkerzlagerstätte im Muschelkalk von Oberschlesien und eine Eisenerzlagerstätte in der Kreide bei Peine in Hannover.

Im Paläozoikum kommen viele Eisen-, Blei-Zink- und Kupfererzlagerstätten vor und zwar in folgenden Gebirgen: Schwarzwald, Rheinisches Schiefergebirge, Harz, Thüringer Wald, Fichtelgebirge, Böhmer Wald, Erzgebirge und Sudeten. Die wichtigsten Erzgebiete sind das Rheinische Schiefergebirge und der Harz mit der anschließenden Mansfelder Mulde. Früher hatte außerdem das Erzgebirge eine große bergwirtschaftliche Bedeutung. Jetzt sind die dortigen Lagerstätten zum größten Teil erschöpft.

Übersicht über die einzelnen Kupfererzvorkommen Deutschlands

Die meisten deutschen Kupfererzlagerstätten sind in der Permzeit entstanden, deren Ablagerungen in „Rotliegendes“ und „Zechstein“ gegliedert werden. Die Sedimente des Rotliegenden (Sandsteine, Schiefertone, Konglomerate) sind kontinentale Bildungen, die sich in variszisch streichenden Sammelmulden ablagerten. Gegen Ende der Rotliegendzeit bildete der deutsche Boden eine aride Landoberfläche, deren Klima die Ansammlung von Kupfererzen begünstigte. Kupferreiche Verwitterungslösungen verdunsteten in flachen Niederungen und setzten dabei Kupfererze ab.

In der Zechsteinzeit wurde die Landoberfläche zum größten Teil durch einen Meerwassereinbruch überflutet, der ein vorher kontinentales Becken ergriff, welches unter das Niveau des Meeresspiegels abgesunken war. Dabei bildete sich ein Mergelschlamm, der die Kupfererze der alten Landoberfläche in gelöster Form aufsaugte. Im Laufe der folgenden geologischen Zeiten bewirkte die Diagenese eine Verfestigung des Mergelschlammes zu Schieferton. Dabei entstanden aus den aufgesaugten Lösungen, die das Lösungsmittel verloren, sulfidische Kupfererze. Damit war die Bildung des weit verbreiteten Kupferschiefers beendet.

Bei dieser Entstehungsweise ist es leicht erklärlich, daß der Kupfergehalt im Kupferschiefer regional sehr verschieden ist. Fast vollständig erzfrei ist der Kupferschiefer am Niederrhein, wo das produktive Karbon seine Unterlage bildet. Dies war offenbar für die Bildung kupferreicher Verwitterungslösungen ungeeignet. An den Rändern des Harzes und des Thüringer Waldes zeigt der Kupferschiefer fast überall einen mäßigen Kupfergehalt, der in früheren Jahrhunderten allenthalben die Veranlassung zu Bergbaubetrieben gegeben hat. Nur in der Mansfelder Mulde ist der Metallreichtum so groß, daß sich ein Bergbau von weltwirtschaftlicher Bedeutung entwickeln konnte.

Einzelne höher gelegene Teile der alten Landoberfläche der Rotliegendzeit wurden erst nach der Bildungszeit des Kupferschiefers bei steigendem Wasserstand überflutet. Es entstanden Kalke, die mit dünnen Lettenbänken wechsellagern. Diese nahmen ähnlich wie der Kupferschiefer kupferhaltige Verwitterungslösungen auf, welche vom benachbarten Festland her in das flache zeitweise fast austrocknende Wasserbecken eindrangen. Auch hier entstanden im Laufe der Diagenese sulfidische Kupfererze in den sogenannten Kupferletten. Diese kommen im Gegensatz zum Kupferschiefer nur in den Randgebieten des Zechsteinbeckens vor und zwar am Ostrand des Rheinischen Schiefergebirges, am Südrand des Frankenwaldes und am Nordostrand der Sudeten. Die meisten Kupferletten gehören dem Unteren Zechstein an; nur am Rande des Rheinischen Schiefergebirges kommen sie auch im Oberen Zechstein vor.

Die Gesteine, welche die alte Landoberfläche bildeten, enthielten an manchen Stellen im Bereich von tektonischen Störungen Zerklüftungszonen, in die unter günstigen Bedingungen von oben her kupferhaltige Lösungen eindringen konnten. Diese gaben die Veranlassung zur Bildung von deszendenten Gängen oder Imprägnationszonen. Derartige Lagerstätten im unmittelbaren Untergrund des Zechsteins treten im Gneiß von Schöllkrippen (Spessart) und im Kulm von Stadtberge in Westfalen auf.

Die vorstehend behandelten, in Verbindung mit der permischen Landoberfläche stehenden Lagerstätten kommen besonders an folgenden Stellen vor (die beigefügten Zahlen entsprechen der Numerierung auf der Übersichtskarte, Figur 84):

Kupferschiefer:

1. Alvensleben	6. Sangerhausen	11. Großkamsdorf
2. Wohlsdorf	7. Rottleberode	12. Ilmenau
3. Golbitz	8. Kyffhäuser	13. Schweina
4. Oberwiederstedt	9. Bottendorf	14. Richelsdorf
5. Mansfeld	10. Gera	15. Hitzerode

Kupferletten:

16. Hasel	18. Frankenberg	20. Bieber
17. Thalitter	19. Haingründau	

Deszendente Gänge unter dem Zechstein:

21. Stadtberge	22. Schöllkrippen

Außer diesen permischen Lagerstätten gibt es noch eine Reihe anderer Kupfervorkommen verschiedenartiger Entstehung. Besonders hervorzuheben sind die Erzgänge im Rheinischen Schiefergebirge. Hauptsächlich handelt es sich dort um Spateisensteingänge (besonders im Siegerland), die untergeordnet Kupferkies führen. Daneben kommen auch reine Kupfererzgänge vor.

Weitere Kupfererzgänge und Kupfererz führende Blei-Zinkerzgänge sind im Frankenwald, dem Erzgebirge und in den Sudeten bekannt geworden.

Besonders hervorgehoben zu werden verdient das Erzlager des Rammelsberges im Harz. Es ist in der Hauptsache eine Blei-Zinkerzlagerstätte, die in zweiter Linie bedeutende Mengen von Kupfererzen enthält.

Sedimentäre Kupfererze kommen ferner im Buntsandstein von Mechernich (untergeordnet neben Bleierzen) und von Wallerfangen vor. In Verbindung mit Eruptivgesteinen (Melaphyr) als Ausfüllung von Blasenräumen kommt Kupfererz bei Oberstein und Wallhausen vor.

Die folgende Übersicht umfaßt die nichtpermischen Kupfererzlagerstätten:

Rheinisches Schiefergebirge:

23. Wipperfürth	28. Werlau (neben Blei-Zink)	32. Wallhausen
24. Mechernich	29. Herbornseelbach	33. Imsbach
26. Antweiler	30. Bergebersbach	34. Bräunigweiler
26. Rheinbreitbach	31. Oberstein	35. Wallerfangen
27. Eitorf		

Zusammen mit Spateisenstein kommen Kupfererze vor in den Siegerländer und Wieder Gängen bei

36. Littfeld	39. Kirchen	41. Oberlahr
37. Gosenbach	40. Wissen	42. Puderbach
38. Neunkirchen		

Harz:

43. Lauterberg	44. Rammelsberg

Frankenwald und Fichtelgebirge:

45. Kupferberg in Franken	47. Ölsnitz (neben Spateisenstein)
46. Steben	

Erzgebirge:

48. Freiberg (neben Blei-Zink)
49. Hohenstein-Ernstthal (neben Blei)
50. Klingenthal

Sudeten:

51. Ludwigsdorf
52. Kupferberg in Schlesien
53. Altenberg (neben Blei-Zink)

Von diesen vielen Kupferlagerstätten haben in den letzten Jahren nur folgende eine wirtschaftliche Bedeutung gehabt:

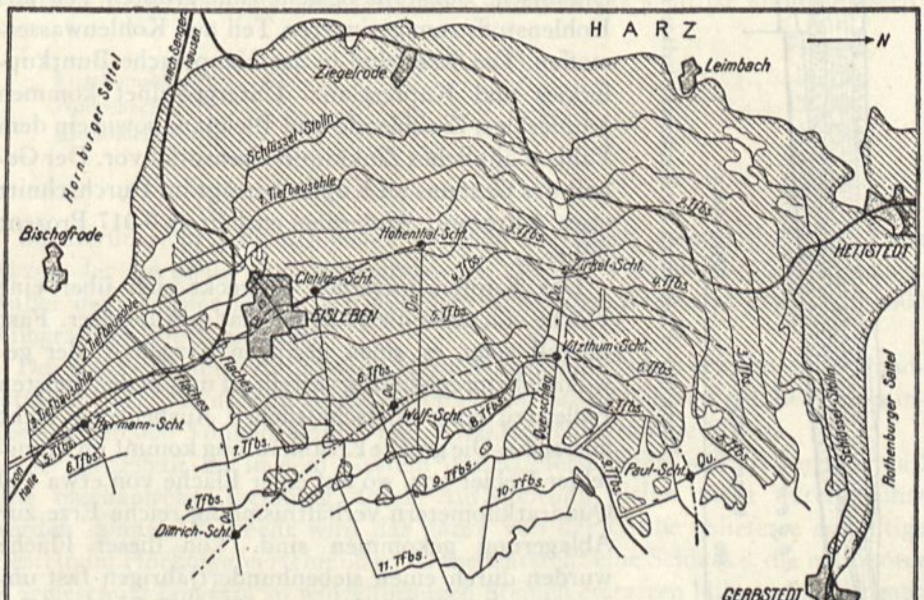
5. Mansfeld
44. Rammelsberg
21. Stadtberge
36–42. Siegerländer und Wieder Gänge

Die Kupfererzlagerstätte von Mansfeld

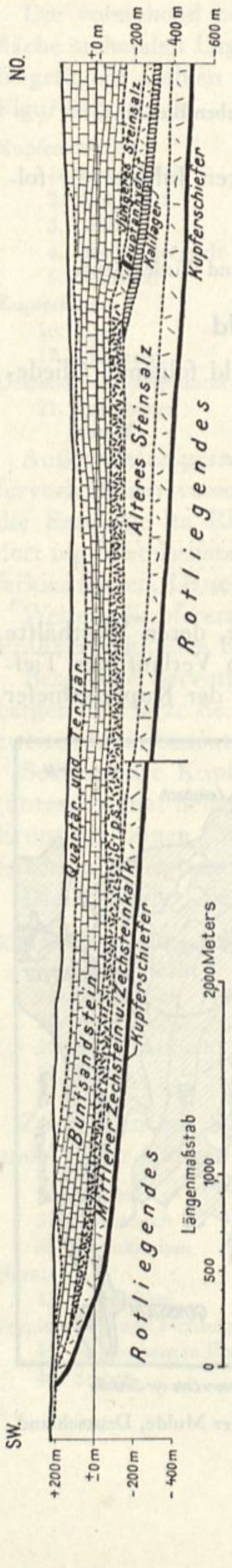
Die Zechsteinformation zeigt in der Gegend von Mansfeld folgende Gliederung:

	Meter
Oberer Zechstein: Steinsalz, Kalisalze, Anhydrit, Salzton	500
Mittlerer Zechstein: Stinkschiefer, Anhydrit, Steinsalz	60
Unterer Zechstein:	
Zechsteinkalk	5
Kupferschiefer	.4
Weißliegendes (diagonal geschichteter Sandstein)	1

Die Schichten sind in der Form einer Mulde abgelagert, deren Westhälfte der Schauplatz des Kupferschieferbergbaues ist. Aus dem Verlauf der Tiefbausohlen (vgl. Fig. 85) ist zu erkennen, in welcher Weise der Kupferschiefer



Figur 85.—Übersichtskarte des Kupferschieferbergbaues in der Mansfelder Mulde, Deutschland.



Figur 86.—Profil durch die Kupferschieferlagerstätte der Mansfelder Mulde. (Nach Fulda.)

nach dem Muldeninnern zu sich einsenkt (vgl. auch das Profil der Fig. 86).

Die Erze kommen in der Hauptsache im Kupferschiefer selbst vor und zwar besonders in den untersten 22 Centimetern dieser Schicht. Stellenweise führen auch Weißliegendes („Sanderz") und Zechsteinkalk („Dachberge") etwas Erz. In der letzten Zeit sind im Mansfeldschen keine Sanderze mehr gewonnen worden; sie spielten in anderen Kupferschiefergebieten eine wesentliche Rolle. Erzhaltige Dachberge machen gegenwärtig 13 Prozent der Mansfelder Förderung aus.

Die Zusammensetzung des Kupferschiefers ist folgende:

	Prozent
Ton. Quarz und sonstige klastische Bestandteile	45
Kalk und Dolomit	28
Organische Substanz	15
Erz	12

Der Kupferschiefer enthält eine reiche Fauna von Ganoidfischen, darunter besonders *Paläoniscus freieslebeni* und eine Flora von Farnen und Coniferen. Die Organische Substanz besteht zum größten Teil aus Kohlenstoff, zum geringeren Teil aus Kohlenwasserstoffen. Die Erze sind in der Hauptsache Buntkupferkies und Kupferglanz. Untergeordnet kommen Kupferkies, Zinkblende und Bleiglanz sowie ein dem Fahlerz ähnliches Zinkkupfereisensulfid vor. Der Gehalt des Gesteins an Kupfer beträgt im Durchschnitt etwa 3 Prozent. Außerdem enthält es 0.017 Prozent Silber.

Das Kupferschieferflöz erstreckt sich über eine Fläche von mehr als 100,000 Quadratkilometer. Fast überall zeigt es einen geringen Erzgehalt, der gewöhnlich unregelmäßig verteilt ist und in den meisten Fällen zu einer wirtschaftlichen Ausbeutung nicht ausreicht. Die größte Erzanhäufung kommt im Mansfelder Gebiet vor, wo auf einer Fläche von etwa 140 Quadratkilometern verhältnismäßig reiche Erze zur Ablagerung gekommen sind. Von dieser Fläche wurden durch einen siebenhundertjährigen fast ununterbrochenen Bergbau ungefähr 117 Quadratkilometer ausgebeutet. Eine Fläche von 8 Quadratkilometern ist durch Aufschlußarbeiten zum Abbau bereitgestellt. Weitere 15 Quadratkilometer sind wahrscheinlich außerdem noch für den Abbau geeignet, aber bis jetzt noch nicht näher untersucht.

Aus der Figur 85 ist die Ausdehnung der Grubenbaue zu ersehen. Das Kupferschieferflöz fällt mit durchschnittlich 5 Grad nach Osten ein und wird durch Tiefbausohlen erschlossen, die in senkrechten Abständen von 63 Metern aufeinander folgen. Gegenwärtig bildet die 11. Sohle den tiefsten Aufschluß (800 Meter unter der Erdoberfläche). Nach Nordosten zu setzt sich der Kupferschiefer über diese Sohle hinaus in bauwürdiger Beschaffenheit nach größerer Tiefe zu fort.

Mit Rücksicht auf das flözförmige Vorkommen des Erzes, das für den Kupferschiefer charakteristisch ist, pflegt man den Metallgehalt je Quadratmeter Flözfläche anzugeben und danach die Abbauwürdigkeit zu beurteilen. Im allgemeinen werden nur Flächen mit mehr als 15 Kilogrammen Kupfer je Quadratmeter abgebaut. Der Durchschnitt der bauwürdigen Flächen enthält etwa 21 Kilogramme Kupfer.

Meist sind nur die untersten 22 Centimeter des Kupferschieferflözes schmelzwürdig. In der Nähe von Verwerfungen („Rücken") findet man Erzanreicherungen, die sich über die ganze Mächtigkeit des Flözes und über Teile des darüberliegenden Kalkagers erstrecken.

Der Bergbau ist in der Hauptsache auf zwei großen Schachtanlagen, dem Wolf- und dem Vitzthumschacht konzentriert. Eine geringere Förderung hat der Klothildenschacht, dessen Baufeld in wenigen Jahren erschöpft sein wird. Wegen Erschöpfung ihrer Baufelder oder wegen Mangel an noch bauwürdigen Erzen wurden in den letzten Jahren Paul-, Zirkel-, Hohenthal- und Hermannschacht eingestellt (vgl. Fig. 85).

Durch die Grubenbaue sind folgende Kupfermengen sichtbar aufgeschlossen:

	Tonnen
Vitzthumschacht	99,720
Wolfschacht	155,736
Klothildenschacht	15,044
	270,500

Bei Berücksichtigung der bisher üblichen Verfahren lassen sich daraus nach Abzug der Bergbau- und Hüttenverluste 200,000 Tonnen Kupfer herstellen. Außer dem Kupfer lassen sich aus dem sichtbaren Erzvorrat etwa 1,100,000 Kilogramme Silber gewinnen.

Der wahrscheinlich vorhandene Metallvorrat in den oben erwähnten 15 Quadratkilometern vermutlich noch vorhandenen bauwürdigen Feld beträgt mindestens 320,000 Tonnen Kupfer und 1,700,000 Kilogramme Silber.

Der Erzgehalt ist in dem Gestein des Kupferschiefers so fein verteilt, daß eine mechanische Trennung durch Aufbereitung bisher nicht durchgeführt werden konnte. Vielmehr wird das ganze von der Grube gelieferte erzhaltige Gestein im Hochofen verschmolzen. Dabei entsteht eine Schlacke, die man unter Wärmeschutz langsam zu würfelförmigen Steinen erstarren läßt, welche in ganz Mitteleuropa als Pflastersteine sehr geschätzt werden.

Von den in Figur 84 unter Nr. 1–15 eingetragenen Kupferschiefervorkommen ist nur die unter Nr. 9 genannte Lagerstätte bei Bottendorf[1] wahrscheinlich dem

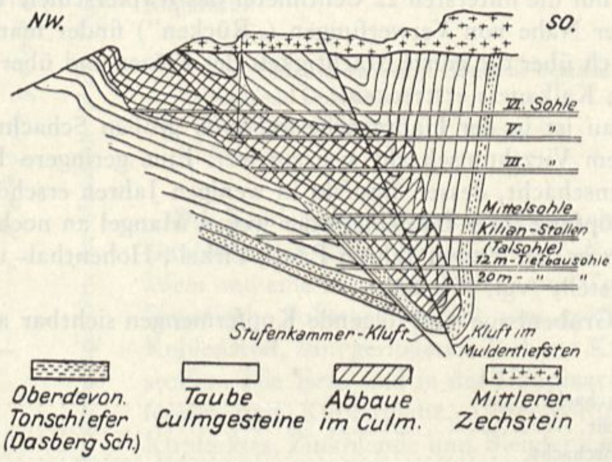
[1] Der Kupfererzbergbau von Bottendorf wurde vor 150 Jahren wegen Wasserschwierigkeiten eingestellt und ruht seitdem.

Mansfelder Vorkommen ebenbürtig. Alle übrigen haben nur wenige Kilogramm Kupfer je Quadratmeter Flözfläche aufzuweisen und sind deshalb unbauwürdig. Auch der in den Jahren 1929 und 1930 versuchsweise wieder betriebene Bergbau im Sangerhäuser Revier erwies sich nicht als rentabel.

Bei den besonders niedrigen Kupferpreisen der letzten Zeit konnte auch der Mansfelder Bergbau nur mit Hilfe einer staatlichen Subvention aufrecht erhalten werden.

Die Kupfererzlagerstätte von Stadtberge in Westfalen

In der Gegend von Stadtberge (am Nordostrande des Rheinischen Schiefergebirges) treten stark gefaltete Schichten des Devon und des Unterkarbon auf, die diskordant von fast horizontal liegenden Zechsteinschichten überlagert werden (vgl. Fig. 87).



FIGUR 87.—Profil durch die Grubenbaue der Grube Oskar bei Stadtberge, Deutschland. (Nach Boden.)

Zwischen den Kalkbänken des Zechsteins kommen Lettenlagen vor, die meist nur 1 bis 5 Centimeter mächtig sind. Stellenweise treten 10 bis 30 solcher Lettenflöze übereinander auf, die einen wechselnden fein verteilten Kupfererzgehalt führen.

Die Hauptmasse des Erzes liegt jedoch nicht im Zechstein, sondern in der Nähe von Spalten in dem vom Zechstein bedeckten Kulm (Unterkarbon). Dieser besteht aus Kieselschiefern und Tonschiefern. Im Bereich der harten Kieselschiefer ist das Gestein längs der Spalten stark zerklüftet. Diese Zertrümmerungszonen des Kieselschiefers sind viefach mit Kupfererzen imprägniert. Der Kupfergehalt des Gesteins beträgt durchschnittlich 1.6 Prozent. Es kommen aber auch wesentlich reichhaltigere Zonen vor. Als primäre Erze treten Kupferglanz und Buntkupfererz auf. Als sekundäre Erze sind Malachit und Kupferlasur häufig.

Nach der Tiefe zu nimmt die Erzführung ab. Die Spalten schließen sich im Devon und sind dann erzfrei.

Die erzführenden Spaltenzonen sind auf eine streichende Erstreckung von 2 Kilometern durch die Gruben Mina, Oskar und Friederike erschlossen worden. Die tiefsten Grubenbaue liegen etwa 40 Meter unter den verschiedenen Stollen, die von den benachbarten tief eingeschnittenen Tälern ausgehen.

Bis zum Jahre 1850 stand die Gewinnung der Erze in den Kupferletten des Zechsteins im Vordergrund. Später wurden nur die in den Spalten des Kulmkieselschiefers auftretenden Erze gewonnen. Bis etwa 50 Meter Tiefe unter der Erdoberfläche waren hauptsächlich sekundäre oxydische Erze vorhanden. In größerer Tiefe setzt die primäre Zone mit sulfidischen Erzen ein, die in der letzten Zeit allein abgebaut wurden.

Infolge Sinkens der Kupferpreise wurde der Bergbau im Jahre 1930 eingestellt. Damals waren noch Erze mit einem Kupferinhalt von 4,000 Tonnen aufgeschlossen. Darüber hinaus kann man einen Kupfervorrat von 6,000 Tonnen als wahrscheinlich vorhanden annehmen.

Die Blei-, Zink- und Kupfererzlagerstätte des Rammelsberges bei Goslar in Hannover

Der Rammelsberg liegt am Nordrande des Harzes. Er wird aus devonischen Schichten (*Cultrijugatus*-Sandstein, *Calceola*-Schichten, Wissenbacher Schiefer) aufgebaut, die auf ein System isoklinaler Sättel und Mulden überschoben sind (vgl. Fig. 88).

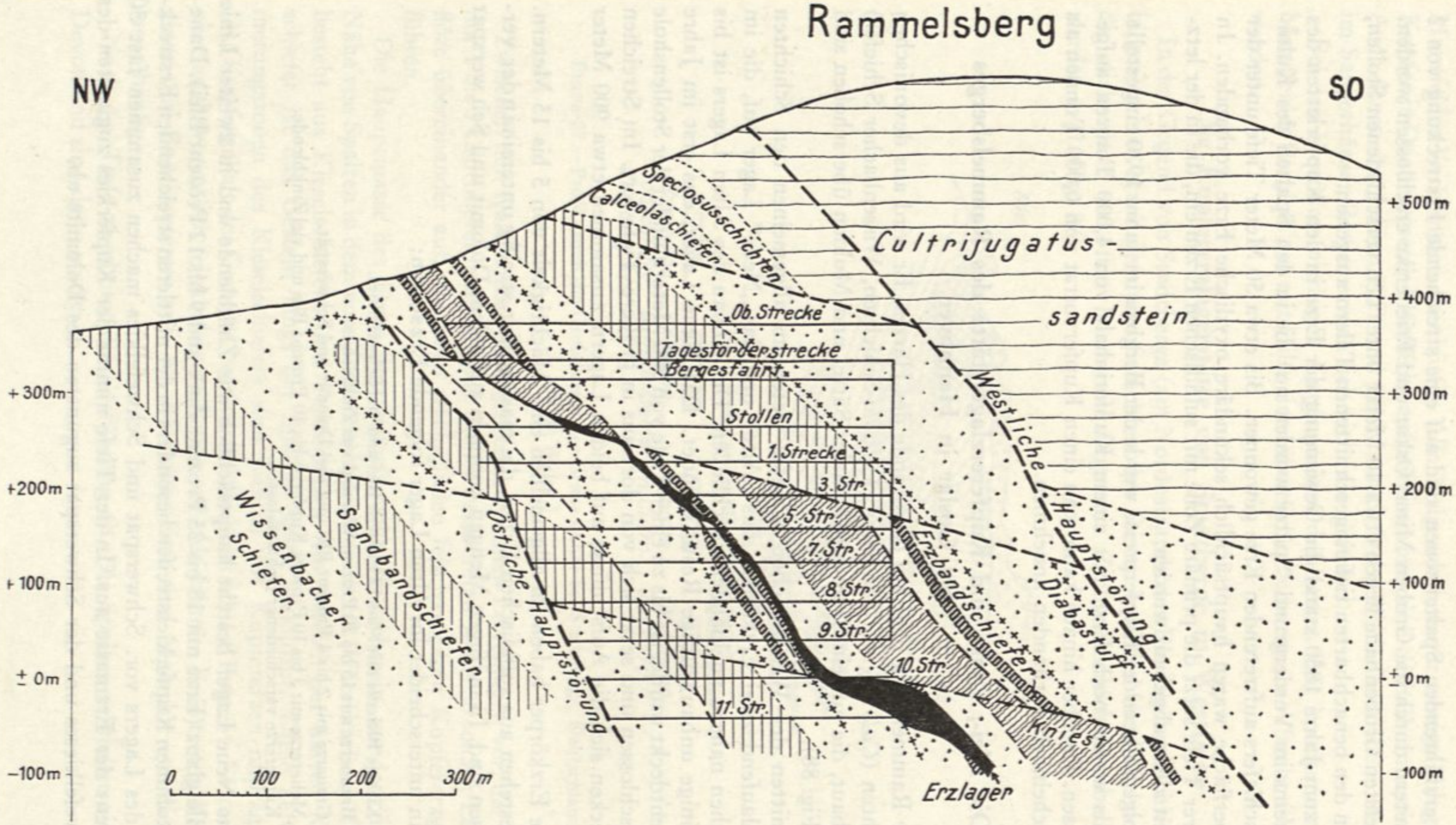
Inmitten der Wissenbacher Schiefer treten im allgemeinen den Schichten gleichlaufend zwei Erzkörper, das „Alte“ und das „Neue“ Lager auf, die im Streichen nahezu aneinander anschließen. Der Abbau des Alten Lagers ist bis auf einige unbauwürdige Reste beendet. Das Neue Lager, das erst im Jahre 1859 entdeckt wurde, ist bis zu einer Tiefe von 300 Metern under der Stollenshole aufgeschlossen und setzt sich von dort aus in größere Tiefe fort. Im Streichen erstrecken sich die Aufschlüsse auf beiden Lagern zusammen etwa 900 Meter weit.

Die Erzkörper haben im allgemeinen eine Mächtigkeit von 5 bis 15 Metern. Sie bestehen aus sulfidischen Erzen, die massig oder streifig untereinander verwachsen sind. In mäßigen Mengen kommen außerdem Dolomit und Schwerspat vor.

Man unterscheidet im Alten Lager folgende Erzsorten:

Kiesige Bleierze mit 8 bis 12 Prozent Blei und viel Schwefelkies.
Braunerze mit 15 bis 20 Prozent Blei und viel Zinkblende.
Grauerze mit 2 bis 4 Prozent Blei und viel Dolomit und Schwerspat.
Meliererze mit 3 bis 10 Prozent Kupfer, 6 bis 10 Prozent Blei und viel Zinkblende.
Kupfererze verschiedener Gehaltsklassen.

Das Neue Lager besteht hauptsächlich aus Zinkblende und in zweiter Linie aus Bleiglanz (Erze mit 18 bis 25 Prozent Zink und 9 bis 12 Prozent Blei). Daneben kommen Kupferkiesstreifen besonders in der mittleren streichenden Erstreckung des Lagers vor. Schwerspat und Schwefelkies machen zusammen fast 50 Prozent der Erzmasse aus. In der Tiefe nimmt der Kupferkies zugunsten des Schwefelkieses und der Schwerspat zugunsten des Dolomits ab.



FIGUR 88.—Profil durch das Neue Lager des Rammelsberges, Deutschland. (Nach W. E. Schmidt.)

Das Erzlager des Rammelsberges ist demnach in der Hauptsache eine Blei-Zinkerzlagerstätte, die untergeordnet Kupfererze führt.

Die Entstehung der Lagerstätte ist umstritten. Die meisten Forscher halten sie für syngenetisch mit dem Nebengestein.

Der zum Abbau im Neuen Lager vorgerichtete Teil des Erzkörpers umfaßt etwa 6,600,000 Tonnen Erz. Davon entfallen schätzungsweise 1,466,000 Tonnen auf Melier- und Kupfererze mit einem Kupferinhalt von 62,600 Tonnen. In größerer Tiefe, also unterhalb der 11. Strecke, der zur Zeit tiefsten Sohle, sind wahrscheinlich bis zu einer Hauptstörung noch 35,000 Tonnen Kupfer zu erwarten. Noch tiefer können weitere beträchtliche Mengen vorhanden sein.

Kupfervorkommen im Rheinischen Schiefergebirge

In den Spateisensteingängen des Siegerlandes tritt Kupferkies nesterweise oder in schmalen Trümern innerhalb der Gangmasse auf. Nur in wenigen Fällen bildet er selbständige Gänge von geringer Erstreckung.

Der Anteil der Kupfererze am gesamten Fördergut beträgt 0.1 bis 0.7 Prozent auf den einzelnen Gruben, im großen Durchschnitt etwa 0.14 Prozent. Die bis 1,300 Meter Tiefe anstehenden Vorräte an Eisenerzen werden auf 100,000,000 Tonnen geschätzt. Demnach darf man mit etwa 140,000 Tonnen Kupfererzen rechnen, die etwa 7,000 Tonnen Kupfer enthalten dürften. Davon entfallen etwa 1,000 Tonnen auf die sichtbaren und 6,000 Tonnen auf die wahrscheinlich vorhandenen Vorräte.

Im Rheinischen Schiefergebirge waren früher auch außerhalb des Siegerlandes einige Gruben im Betrieb die Kupfererze als Haupt- oder als Nebenprodukt förderten. Die bedeutendste war die Grube Danielszug bei Wipperfürth.

Zur Geschichte des deutschen Kupfererzbergbaus

Die Entdeckung der meisten deutschen Kupferlagerstätten erfolgte bereits in weit zurückliegender Zeit, aus der nur verhältnismäßig spärliche Nachrichten vorliegen. Ein besonders hohes Alter hat der Bergbau des Rammelsberges, der vor etwa 1,000 Jahren begonnen hat und wegen seiner reichen Erträge an Silber und anderen Metallen von großer Bedeutung in der deutschen Geschichte gewesen ist.

Der Bergbau in Mansfeld und in Stadtberge hat vor etwa 700 Jahren begonnen. In der damaligen Zeit sind vermutlich auch die meisten übrigen deutschen Kupfererzlagerstätten entdeckt worden.

Bis in das 19. Jahrhundert hinein waren sehr viele kleine Kupferbergwerke im Betrieb. Die moderne Wirtschaftsentwicklung brachte es mit sich, daß sich die auf minderwertigen Lagerstätten arbeitenden kleineren Betriebe nicht halten konnten. Statt dessen entwickelten sich auf den besten Lagerstätten (Mansfeld, Rammelsberg) in der zweiten Hälfte des 19. Jahrhunderts Großbetriebe mit stark ansteigender Produktion. Vor 1850 lieferte der Mansfelder Bergbau in 50 Jahren ebensoviel Kupfer wie jetzt in einem Jahre.

Neue Kupfererzlagerstätten sind in den letzten Jahrhunderten in Deutschland nicht mehr entdeckt worden.

Statistische Angaben

Die Förderung von Kupfererzen in den letzten Jahren geht aus folgender Tabelle hervor:

Förderung von Kupfererzen in Deutschland, 1924–33, in Tonnen

Jahr	Mansfeld	Rammelsberg	Stadtberge	Rheinisch Schiefergebirge [a]	Schlesien [b]	Oberharz [c]	Summe Deutschland
1924.........	734,600	28,198	19,338	9,003	464	438	792,041
1925.........	728,600	28,216	42,314	10,472	499	313	810,414
1926.........	830,000	35,255	51,027	17,267	23	36	933,608
1927.........	850,400	31,011	49,492	21,053	....	133	952,089
1928.........	829,000	[d]7,308	58,475	11,557		14	906,354
1929.........	[e]939,100	13,963	55,840	16,749	....	56	1,025,708
1930.........	[f]808,760	10,943	14,899	7,650	....	....	842,252
1931.........	860,900	15,457	....	10,877	....	15	887,249
1932.........	952,250	11,838		992	....	1	965,081
1933.........	997,070	9,239	....	601	....	....	1,006,910

[a] Vorwiegend Siegerland.
[b] Von der Grube Kupferberg in Schlesien.
[c] Aus dem Oberharzer Blei-Zinkerzgängen.
[d] Seit 1928 werden die Meliererze in der Statistik nicht mehr als Kupfer-, sondern als Blei-Zinkerze angegeben.
[e] Einschliesslich 420 Tonnen aus dem Sangerhäuser Revier.
[f] Einschliesslich 2,201 Tonnen aus dem Sangerhäuser Revier.

Auf den Kupferhütten in Hettstedt (für Mansfeld), in Oker (für den Rammelsberg) und in Stadtberge wurden folgende Mengen Kupfer aus eigenen Erzen hergestellt:

Herstellung von Kupfer, 1924–32, in Tonnen

Jahr	Hettstedt	Oker [a]	Stadtberge	Summe
1924............	18,541	305	350	19,196
1925............	19,124	412	350	19,886
1926............	19,946	589	470	21,005
1927............	23,038	870	485	24,393
1928............	20,716	986	590	22,292
1929............	22,224	1,033	580	23,837
1930............	20,356	1,981	480	22,817
1931............	25,056	1,601	440	27,097
1932............	25,000	1,152	....	26,152

[a] Ein Teil des Kupferinhaltes der Erze des Rammelsberges wird zu Kupfersulfat verarbeitet.

Daneben wurden auf verschiedenen deutschen Hütten größere Mengen Kupfer aus fremden Erzen, fremden Zwischenprodukten und aus Altmaterial erzeugt.

Der Kupferinhalt der Erze des Rheinischen Schiefergebirges, die in der obigen Hüttenstatistik nicht berücksichtigt sind, beträgt etwa 300 Tonnen im Jahr.

Im ganzen hat der deutsche Bergbau im Laufe der Jahrhunderte die Erze für ungefähr 1,600,000 Tonnen Kupfer geliefert, davon die Hälfte in den letzten 50 Jahren.

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Copper ores of Great Britain

By Henry Dewey

Geological Survey of Great Britain, London

During the first half of the 19th century Great Britain contributed more than half of the world's output of copper ores, the greater part coming from the Cornish mines; today the proportion is insignificant. The output from Cornwall fell from 184,858 tons in 1854 to only a few tons in 1932; the world's output in the same years was 291,000 and over 3,000,000 tons respectively. The origin of copper mining in Cornwall and Devon is unknown, but it is not unlikely that copper ores were collected in the bronze age. During the middle part of the 18th century the quantity sold was over 700,000 tons, and from 1771 to 1838 some 5,000,000 tons was produced. In addition to Cornwall and Devon copper ores have been worked principally in Anglesey, North Wales, the Lake district, and some of the Midland counties.

The copper occurs as lodes, as impregnations of the country rock, and as pipes and other irregular-shaped bodies.

Cornwall and Devon

In Cornwall and Devon (fig. 89) the ore occurs in lodes traversing Paleozoic slates and phyllites surrounding and in many places metamorphosed by granite masses, and also locally in the granite itself. The vertical range of the copper ores has been indicated in several deep mines and appears to be about 2,500 feet. Downward it is associated with cassiterite, and upward it gradually merges into a zone of mixed sulphides of copper, zinc, and lead (figs. 90 and 91).

Secondary alteration was a characteristic phenomenon, and three zones of ores were proved—(1) the uppermost or zone of oxidized ores, (2) the zone of sulphide enrichment, and (3) the zone of primary sulphides. The most abundant ore was the primary sulphide, chalcopyrite or copper pyrites, the "yellow ore" of the miner.

The nature of the country rock affected the deposition of the ore. The most productive lodes occurred in blue-gray argillaceous slates of fine grain and in a state of decomposition, but harder and darker slates were less productive. Where lodes traverse igneous rocks the principal copper ore is the vitreous variety—indeed, in several mines it was found to be the only ore in granite.

The productive localities in Cornwall and Devon are adjacent to granite masses (see fig. 89), but they are restricted to small areas and are by no means uniformly spread through the granite tracts. The mineralized belt traverses the peninsula in a northeasterly direction and is normally about 8 miles in breadth. This belt curves and is studded with rich patches separated by less rich or even barren stretches. Most productive of copper ores among these patches was the district near Redruth and Camborne, which yielded 4,500,000 tons of ore in 90 years. The next richest part lay south of the St. Austell granite, near Tywardreath and St. Blazey, with 750,000 tons; and the third was southeast of the Bodmin Moor granite, with 600,000 tons.

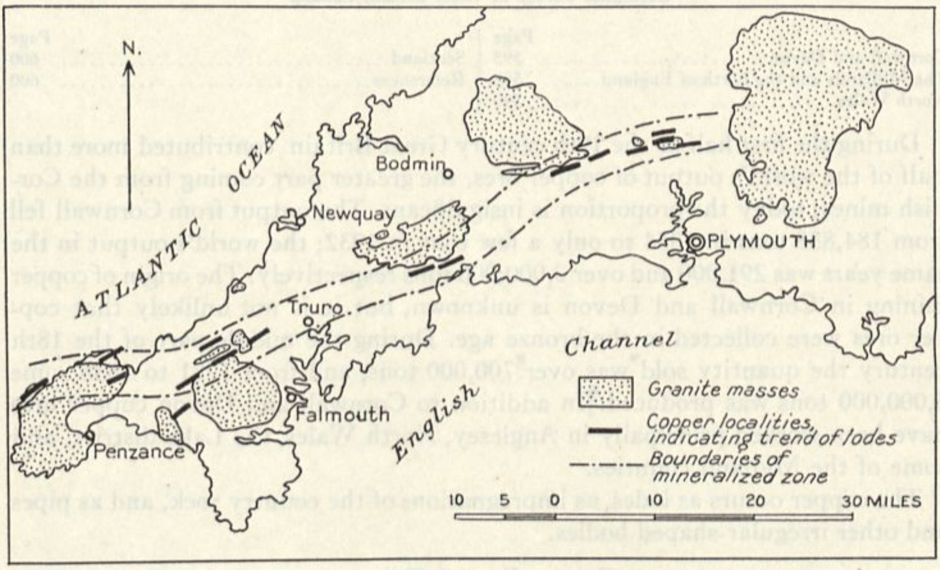

FIGURE 89.—Sketch map of Cornwall and part of Devon, England, showing the copper localities and the trend and position of the lodes relative to the granite masses.

Most of the copper lodes were fissures with clean-cut walls, but brecciated and impregnated walls were not unknown. The average width varied in different districts and ranged from 1.6 to 4.8 feet. They tended to be wider in slate than in granite, the average being 3.75 and 3.18 feet respectively. Of 282 lodes 117 dipped north, 90 south, and the rest in other directions (5, p. 241).

During recent years in the mineralized area around Carn Brea two series of lodes have been proved to dip respectively to the north and to the south. They differ from each other in their mineral contents. Those that dip to the north are characterized by the abundance of mixed sulphide ores (chalcopyrite, pyrite, etc.) in association with arsenide (mispickel) and tungstates (wolfram and scheelite) but are less rich in cassiterite than those that dip to the south. The latter are poor in sulphides, arsenide, and tungstates. The gangue minerals also present group characters, quartz with schorl occurring more commonly in the northward-dipping lodes, whereas those dipping south consist of chlorite and scattered bunches of fluorspar.

Hunt kept a record of the lives of Cornish copper mines and found that 35 mines lasted 20 years, 40 mines 10 years, 31 mines 5 years, and 114 mines less than 5 years.

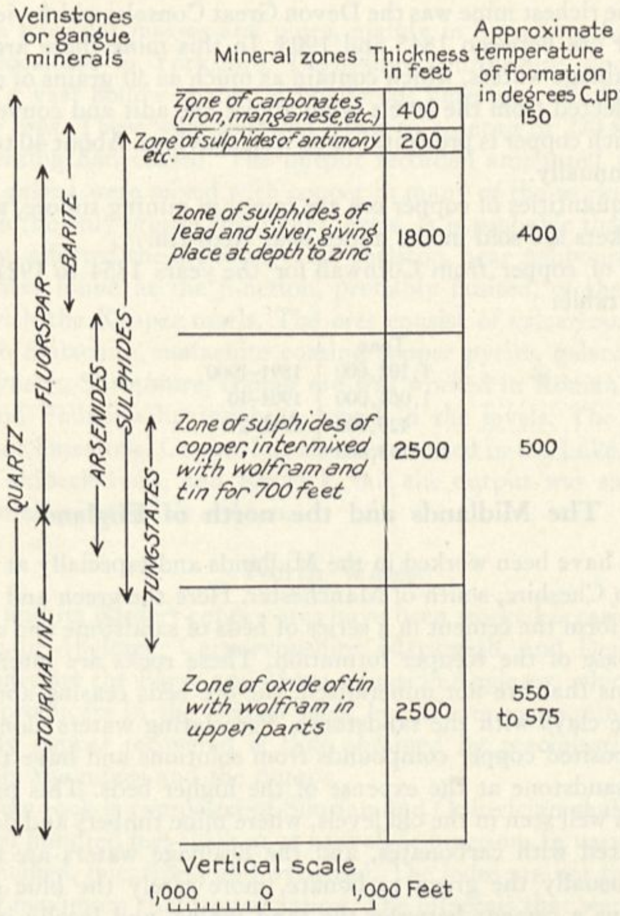

FIGURE 90.—Vertical distribution of mineral zones in Cornwall. (After H. Dewey (7).)

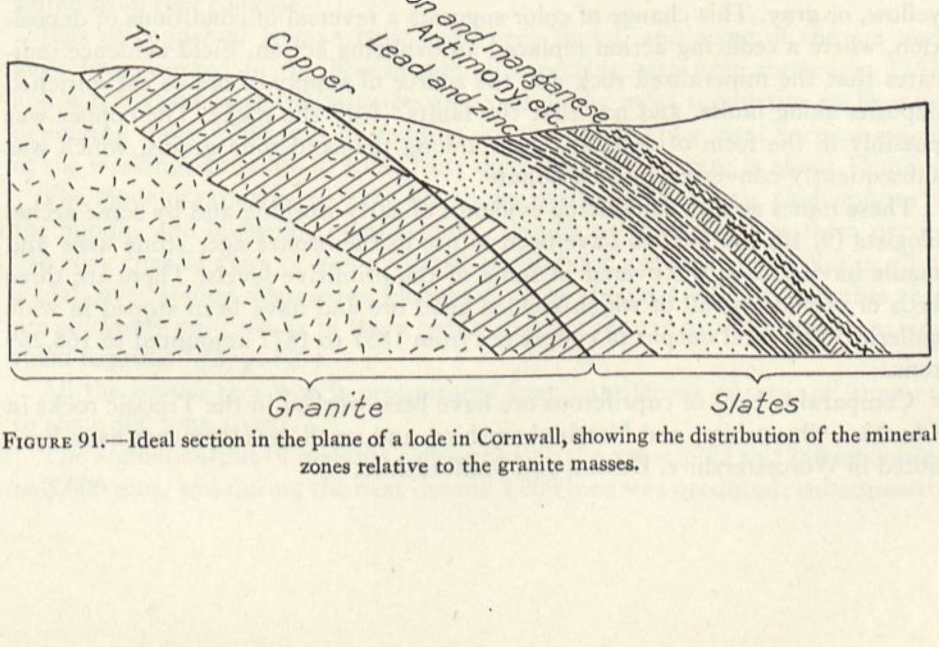

FIGURE 91.—Ideal section in the plane of a lode in Cornwall, showing the distribution of the mineral zones relative to the granite masses.

In Devon the richest mine was the Devon Great Consols, which yielded 742,400 tons of copper ore between 1845 and 1903. In this mine there are 40 miles of levels. The drainage waters, which contain as much as 30 grains of copper to the gallon, are collected from the levels lying above the adit and conveyed through troughs, in which copper is precipitated on iron shavings. About 40 tons of copper is recovered annually.

Only small quantities of copper ore are raised in mining tin ore, and occasionally small packets are sold in the mines near Redruth.

The output of copper from Cornwall for the years 1854 to 1921 is given in the following table:

	Tons		Tons
1854–60	1,102,000	1891–1900	45,000
1861–70	1,064,000	1901–10	33,000
1871–80	425,000	1911–21	about 5,000
1881–90	143,000		

The Midlands and the north of England

Copper ores have been worked in the Midlands and especially at the Alderley Edge mines, in Cheshire, south of Manchester. Here the green and blue carbonates of copper form the cement in a series of beds of sandstone and conglomerate lying at the base of the Keuper formation. These rocks are interbedded with clays and loams that are not mineralized, the ore beds ceasing abruptly at the junction of the clays with the sandstones. Percolating waters along such junctions have deposited copper compounds from solutions and have thus enriched the seams of sandstone at the expense of the higher beds. This process is still going on and is well seen in the old levels, where mine timbers and disused implements are coated with carbonates, and the drainage waters are tinted green.

The ore is usually the green carbonate, more rarely the blue carbonate of copper. It forms a cement between the sand grains, and locally it completely envelops them. The sandstones at the base of the Keuper are normally stained red by oxides of iron, but where copper ores occur the sandstones are white, yellow, or gray. This change of color suggests a reversal of conditions of deposition, where a reducing action replaced an oxidizing action. Field evidence indicates that the mineralized rock was the source of supply of ore to the enriched deposits along faults, and not that the faults "fed" the rocks. The copper was possibly in the form of detrital pyrite among the sandstone grains, which was subsequently converted into carbonate.

These mines supply convincing evidence of early working and by some archeologists (9, 10) are held to have been in use in the bronze age, stone axes and mauls having been discovered in some of the primitive levels. There are three beds of ore bodies, all of which yielded good ore and have been stoped in wide galleries. The total output of copper ore from 1857 to 1877 amounted to 168,269 tons.

Comparable beds of cupriferous ore have been worked in the Triassic rocks in Cheshire, Shropshire, and Nottinghamshire, and small developments have been noted in Worcestershire, Devon, and Staffordshire.

Copper in irregular masses and pipes, mainly in limestone, has been worked at several localities in Yorkshire, Derbyshire, Shropshire, and Staffordshire. At Ecton a vast hollow in the Carboniferous limestone was found to be filled with copper ores. These were followed down to a depth of 220 fathoms, but by 1820 all working had ceased. The output recorded amounted to 60,000 tons. Blende and galena were mixed with copper in many of the workings and appear to have been the only ores in the higher levels. It is probable that secondary enrichment had affected the ore locally. At Snelston, near Ashbourne, Derbyshire, copper ore was found at the junction, probably faulted, of the Carboniferous limestone with the Keuper marls. The ores consist of calcareous sandstone cemented with malachite, malachite coating copper pyrite, galena, and cerusite. At Llanymynech, Shropshire, copper ore was worked in Roman times, coins of Antonius and Faustina having been found in the levels. The lodes occur in Carboniferous limestone. Copper has also been raised in the Lake district around Coniston, Caldbeck Fells, and Keswick, but the output was small. There has been some mining in the Isle of Man.

North Wales

In Wales and its borders copper ores have been worked occasionally at many localities, as in Anglesey, Carnarvonshire, Merioneth, and Denbighshire. The principal mines are the Parys and Mona mines, in Anglesey, which were some of the largest producers in the British Isles, but of late years mining has ceased, and the only copper recovered is that obtained by precipitation from water draining from the mines and the dumps.

The country rock is composed of Silurian and Ordovician shales with a sill of felsite several hundred feet thick at or near their junction. In varying degrees the rocks are silicified, micacized, and pyritized. The lodes are not true fissure veins but zones of maximum chalcopyritization. The minerals that were found on any considerable scale are iron pyrites, chalcopyrite, chalcocite, blende, and galena, the ore being a complex sulphide. There are two great open-cast pits which resulted from roof collapse.

Pigs of copper of Roman type have been found, and some of the ore may have been worked in the bronze age. Prospecting was next started in 1757, and a few years later the mine became one of the most productive in Europe, delivering some 3,000 tons of metallic copper yearly. The total vertical extent of the workings amounts to 1,050 feet; their horizontal extent is about 1½ miles.

The mode of occurrence of the ore shows pyrite on the north, chalcopyrite in the middle, and bluestone on the south, though no part was free from pyrite. "In rock that is more or less pyritized throughout are great lenticular or ellipsoidal, overlapping aggregates, elongated along the strike, of pyrite cubes that are so closely crowded as to leave barely matrix (mostly quartz) enough to bind them together" (3, p. 827).

All the copper now won is precipitated from cupriferous waters and amounts to some 300 tons a year.

The annual output of metallic copper during the years 1773 to 1785 amounted to 3,000 tons, and during the next decade 2,000 tons was produced; subsequently there was a sharp decline, but from 1855 to 1880 the output was 158,500 tons (2, p. 36).

Several small mines have been worked along lodes in the lower Paleozoic rocks of North and Mid Wales, but many were exploited primarily for gold, and the output of copper was small.

Scotland

In Scotland a number of copper deposits have been worked but only on a small scale and not for many years. There is no record of the output, which was inconsiderable. No mining for copper has been done during the present century except a brief and unprofitable trial at Kilfinan, in Argyllshire, and an attempt to reopen the old mine at Sandlodge, in Shetland.

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Giacimenti cupriferi in Italia

Da Michele Taricco
Roma

L'Italia è povera in minerali di rame, per quanto questi si presentino disseminati in molte località e in vari tipi di giacimenti; tra questi si possono distinguere: (*a*) giacimenti nelle rocce basiche, specialmente ofiolitiche; (*b*) giacimenti nelle rocce acide o nella zona circostante metamorfica; (*c*) giacimenti filoniani. Data la grande brevità richiesta per la presente nota, non si possono dare che alcuni cenni per i giacimenti coltivati e qualche indicazione di località per quelli che non lo sono.

(*a*) Numerosi giacimenti cupriferi, di varia importanza, sono in relazione stretta con rocce ofiolitiche, intercalate ai terreni sedimentari eocenici (secondo alcuni cretacei) in molti punti dell'Appennino, della Liguria e della Catena metallifera toscana; si tratta di lherzoliti, peridotiti, eufotidi e diabasi, più o meno serpentinizzate, in forma di lenti e, nell'interno di queste, anche di dicchi (di diabase entro l'eufotide, di eufotide entro la serpentina nera o bastitica, in cui per la maggior parte è convertita la lherzolite). Nell'eufotide e nel diabase e anche al contatto cogli scisti e coi calcari dell'eocene compaiono calcopirite, erubescite e calcosina, spesso con pirite, raramente con blenda, galena, rame nativo, disseminati in vene o in masse globulari o lentiformi di dimensioni svariatissime; la roccia inglobante è in quest'ultimo caso una argilla steatitosa di decomposizione della roccia basica. La più importante di tali lenti è stata quella di Montecatini Val di Cecina, che in mezzo secolo diede 30,000 tonnellate di rame metallico. Giacimenti di questo tipo furono o sono in coltivazione a Libiola in Liguria, alle Cetine in Toscana ed in ricerca ad Impruneta, Livorno, Pomarance, Roccastrada, ecc.

In relazione a rocce basiche (prasiniti) sono i giacimenti del Beth e di Ollomont nelle Alpi piemontesi, quelli di pirite cuprifera in prasiniti e ofioliti di Predoi-Valle Rossa nelle Alpi venete e quello di solfuri misti in diabasi di Rosas in Sardegna.

(*b*) Nella Sardegna centrale, tra il grande massiccio granitico corso-sardo, che quivi culmina al Monte Gennargentu e la sua ricomparsa ad ovest di Sorgono si ha un'estesa striscia di rocce paleozoiche, più o meno metamorfosate in scisti cristallini, corneane ecc., riferibili al siluriano (zone a *Monograptus* a Gadoni, Seulo); essa è attraversata da frequenti dicchi di porfidi prevalentemente quarziferi; in essi e più nella loro vicinanza si hanno zone estesamente, se non intensamente, mineralizzate a solfuri (blenda, galena, pirite, calcopirite) e magnetite; una parte è di metasomatismo di banchi calcarei, con presenza di silicati ferro-calciferi; una parte ha carattere di disseminazioni o di venature ed anche di filoni. I solfuri si trovano commisti; la calcopirite prende talora il sopravvento, come a Fontana Raminosa (Gadoni); è notevole il fatto che la calcopirite ha quivi un elevato tenore in argento.

Uno dei giacimenti più interessanti per giacitura e per bellezza di minerali (specialmente dell'azzurrite) è quello venute in luce da una ventina d'anni a Calabona, a 3 kilometri a sud di Alghero, in Sardegna. Quivi una intrusione di porfirite quarzosa micacea, più o meno caolinizzata, potente da 100 ad oltre 1,000 metri ed affiorante per 3 o 4 kilometri attraversa dei calcari triassici, coperti poi, come la porfirite, da trachiti. Al contatto del calcare colla porfirite si interpongono talora sottili zone di arenarie triassiche più antiche ed altre di scisti paleozoici; anche quando queste intercalazioni mancano il contatto tra porfirite e calcare avviene colla interposizione di una salbanda caotica, talora con ciottoli di calcare e di porfirite, che è ritenuta il prodotto di alterazione degli scisti paleozoici trascinati nell'ascensione della massa porfiritica. Il giacimento finora coltivato è in relazione ad un'apofisi della porfirite fra i calcari e si trova nella zona del contatto entro l'argilla caotica o entro la porfirite, talora anche in masse isolate entro il calcare, non lontano dal contatto stesso. I lavori sono ancora relativamente superficiali; nella zona di ossidazione si hanno limonite, ossidi di manganese, malachite, azzurrite, crisocolla, cuprite, rame nativo, quarzi diasprigni, gessi; nella zona di cementazione, più ricca, covellina in grossi cristalli con pirite, calcosina, rara galena; in un cantiere anche un po' di enargite; ganghe di calcite, argilla, porfirite, ossidi di ferro e di manganese. Un'esplorazione in profondità trovò pirite cuprifera. Notevole è il fatto che nel calcare non vennero trovati minerali che accennino ad un'azione metamorfica per parte della porfirite. Quanto alla genesi è dubbio se essa si debba ascrivere a segregazione magmatica o ad acque termo-minerali susseguenti alla intrusione. I tenori della produzione raggiunsero anche il 26 per cento di metallo.

Collegato ad una roccia sienitica è il giacimento di magnetite con calcopirite di Traversella (ben noto ai mineralogisti), attribuito a fenomeni pneumatolitici.

(*c*) Una certa importanza hanno avuto in passato tre filoni quarzosi cupriferi (pirite e calcopirite talora anche calcosina, rame nativo e tracce di blenda e galena) in Toscana, l'uno a Boccheggiano, tra rocce calcareo-scistose dell'eozene a tetto e scisti permiani o calcari retici a letto, gli altri due a sud di Massa Marittima, di cui l'uno, detto di Serrabottini, tra le formazioni identiche a quelle di Boccheggiano; l'altro, di Fenice-Capanne Vecchie, tutto entro la formazione eocenica e come interstratificato ad essa. Per tutti e tre i filoni si notano fenomeni di metamorfismo dei sottili banchi originariamente calcarei intercalati agli scisti eocenici ed ora silicizzati o silicatizzati in pirosseni, epidoto, granati, mentre gli scisti sono talora caolinizzati. Il minerale di Fenice-Capanne Vecchie dopo la cernita del ricco è trattato in roste, di cui si fa un cenno in fine.

Altri filoni cupriferi sono stati in coltivazione in Sardegna a Tertenia (calcopirite) od in esplorazione a Torpè (calcopirite e carbonati) e ad Ozieri (calcopirite, crisocolla, carbonati ecc.).

Nulla di notevole per quanto riguarda i metodi di ricerca e di coltivazione. Per i trattamenti si può forse ricordare che a Traversella venne impiegata nella seconda metà del secolo scorso la prime cernitrice magnetica, dovuta a Quintino Sella, per la separazione della magnetite dalla calcopirite e sterili.

Pei minerali di rame poveri della miniera Fenice-Capanne ed in passato per quelli di Boccheggiano, il sistema di trattamento è quello idro-metallurgico detto delle roste notevolmente perfezionate dal Sig. Conedera; consiste nel disporre in cataste regolari delle alternanze di vario spessore di fascine e di minerale cuprifero in pezzature appropriate per l'altezza totale di 4 metri; accese le fascine si regola la loro combustione assieme a quella dello zolfo in modo che essa avvenga lentamente, in 7 a 8 mesi, colla solfatizzazione dei solfuri di rame e di ferro; dopo raffreddata la catasta è sottoposta alla lisciviazione, lenta od intensiva, che asporta in soluzione i sali di rame, i quali poi vengono precipitati a mezzo di rottami di ferro (cementazione). I particolari sono esposti in una nota dell'Ing. Atollico (9) e riportati da me (8).

Il processo di lisciviazione-cementazione è pure applicato a Mestre alle ceneri di piriti cuprifere; il rame bruto (cemento di rame) a circa 80 a 84 per cento di rame così ottenuto figura a parte nella statistica.

L'industria del rame in Italia risale alla preistoria; ebbe periodi fiorenti in Etruria (Toscana) dall'undecimo al sesto secolo avanti Cristo, con fonderie a Populonia e forse anche all'Isola d'Elba. Anche in Sardegna si hanno tracce di lavorazioni preromane, dell'età dei Nuraghi. Cadute in seguito sotto Roma l'Etruria e la Sardegna, la loro attività mineraria si affievolisce; risorge per un po' nel medio evo e fiorisce verso il 1200 a Massa Marittima; in Sardegna hanno sviluppo i lavori sotto i Pisani, ma sono specialmente volti a minerali di argento e di piombo. Attualmente l'industria del rame ha poca importanza in Italia rispetto ai suoi bisogni ed alla produzione mondiale.

Produzione di rame dell'Italia, 1926–31, in tonnellate metriche

	1926	1927	1928	1929	1930	1931
Minerali di rame.	13,346	13,556	7,596	11,721	17,728	13,324
Rame in pani.	420	450	900	539	262	721
Cemento di rame.	267	824	2,178	3,064	2,852	2,309

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Copper deposits of Norway

By Steinar Foslie
Geological Survey of Norway, Oslo

Main features of the geology

The following schedule and the accompanying general map (pl. 33) give the necessary orientation for a summary of the copper deposits of Norway.

Permian: Alkaline eruptive province of the Oslo district.

Devonian: Scattered fields of sediments, mainly sandstones, little or not at all affected by metamorphism, younger than the main phase of mountain folding.

Discordance.

Cambrian-Silurian: Different marine sediments, thin and unmetamorphosed east of the geosyncline, extremely thick and more or less crystalline within the geosyncline. Spilitic lavas in lower Ordovician. Great masses of basic and acidic intrusives along the mountain chain. Overthrusts toward the east.

Small unconformity.

Eo-Cambrian: Sparagmite formation, a thick series of arkoses, sandstones, conglomerates, etc., mainly of continental origin.

Great pre-Cambrian peneplain.

Pre-Cambrian: Younger granites, very great masses. Telemark formation, metamorphosed effusives (quartz porphyries and greenstones) and thick series of sediments, mainly quartzites and mica gneisses.

Discordance.

Archean: Kongsberg formation, profoundly metamorphosed deep-seated igneous rocks, low in Potash. Possibly also several unclassified gneisses and granites.

The age of the Raipas formation, in the northermost part of Norway, is not yet certain. Most probably, perhaps, it is pre-Cambrian.

General distribution of copper ores

As in other countries, copper has been deposited under the most varying conditions. We find it in all the formations enumerated, except the Sparagmite formation and the Devonian, both of which consist mainly of continental sediments cut by very subordinate eruptive rocks and without ore deposits of any kind. Most of the copper now known in Norway is genetically connected with the eruptive rocks of the mountain chain, forming more or less cupreous pyrite and pyrrhotite deposits of a few closely related types. In the older formations copper deposits are also numerous, more varied, locally richer, but nowhere so large as some of those of the mountain chain. The principal ones are found within certain metallogenetic provinces in the Telemark formation, the Raipas formation, and the Porsanger district.

The copper-bearing deposits may be grouped as follows:

Copper the only or main product of economic value
Copper in pyritic ores, whose sulphur is also utilized.
Copper as a byproduct from sulphidic nickel ores.
Copper as a byproduct from sulphidic zinc-lead ores (unimportant).

Main groups of copper mines and deposits

Archean

In the regions known to belong to the oldest Archean (Kongsberg formation, etc.) copper deposits are insignificant. They occur mainly in the extensive sulphidic impregnation bands, known as "fahlbands," with a low copper content, and are no longer worked. Copper is produced, however, as a byproduct from the nickeliferous pyrrhotite deposits, for which Norway was known long before the discovery of Sudbury. These deposits are very similar to the marginal deposits of Sudbury, but much smaller. Flåt mine (the largest) and Ringerike mines occur in this oldest Archean; others (Hosanger mines) are found in the unclassified Archean, but none in the Telemark formation. Smaller deposits of this type are also present, however, in younger noritic rocks of the mountain chain.

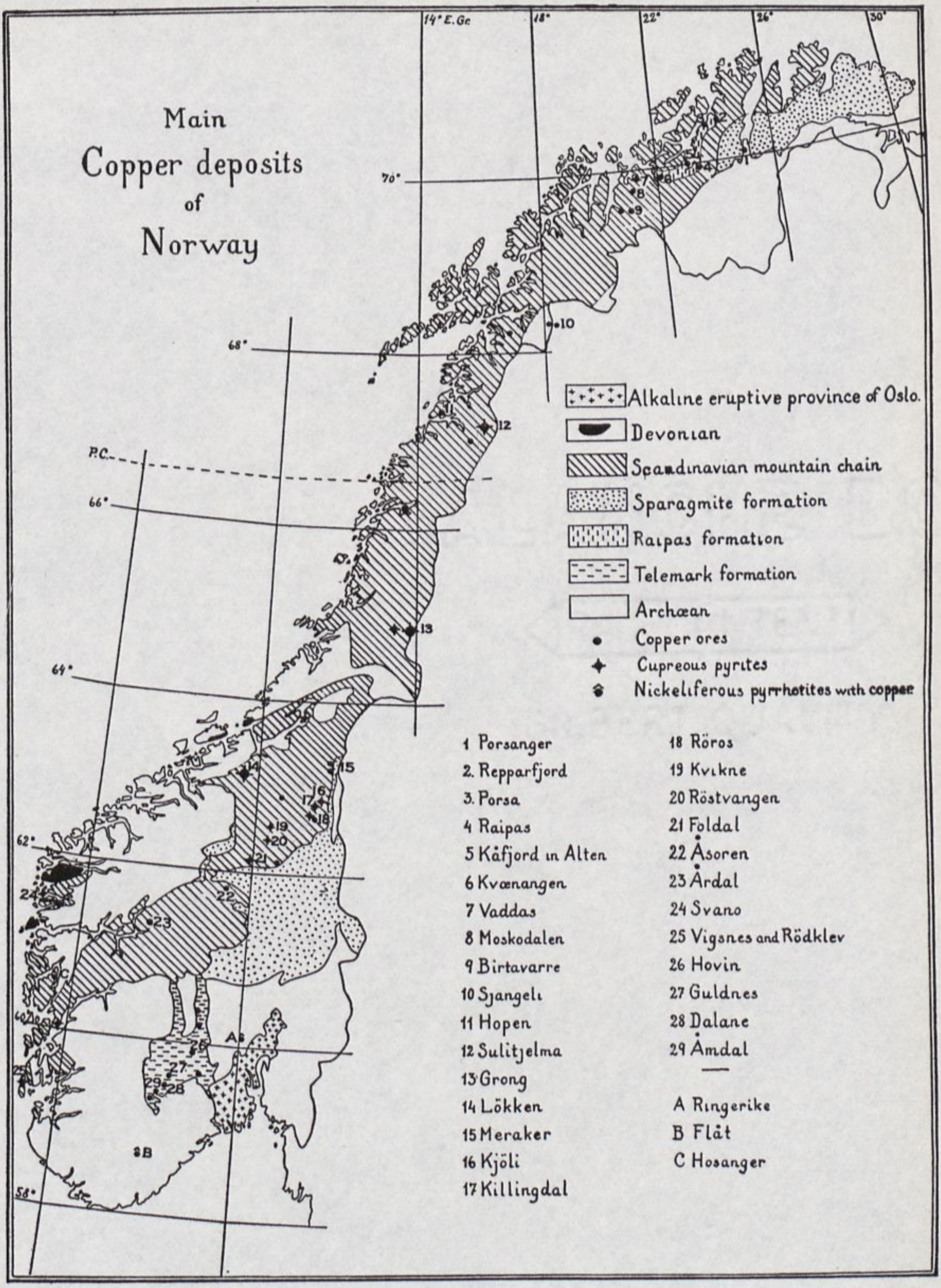
The ore in sight in deposits of this type amounts to about 1,500,000 tons, which besides its nickel content carries 0.8 to 1.1 percent of copper (about 13,000 metric tons).

Telemark formation

The numerous deposits of the Telemark formation constitute a well-defined metallogenetic province, with copper as the main metal but also with deposits of molybdenite, bismuthinite, fluorspar, etc., and locally of silver and gold. Very characteristic is the almost complete absence of pyrite, pyrrhotite, and sphalerite, elsewhere the commonest minerals. Most of the deposits occur within a broad border zone along the surrounding massif of younger granites. They are typical quartz veins with chalcopyrite, primary bornite, and some chalcocite.

Most considerable is the Åmdal mine, whose main vein has a regular length of at least 1,400 meters, parallel to the schistosity of a mica gneiss near the granite contact. It has yielded on the average 60 kilograms of copper per square meter of vein. The ore hitherto mined has contained about 10,000 tons and yielded 8,000 tons of metallic copper. Copper in sight above the adit is calculated at 7,000 tons and to a vertical depth of 100 meters below the adit probably 5,000 tons additional. Figures are not available for the other deposits, but the individual veins are considerably smaller.

Several miles from this contact we still find copper-bearing quartz veins, many of them with a higher content of silver and gold. These veins occur commonly within or near intrusive amphibolites, and their genetic connection with the veins mentioned above has not yet been proved. A curious deposit is that of the Dalane mines, according to C. Bugge, where native copper and silver have impregnated sandstone along a greenstone contact.


Main
Copper deposits
of
Norway
14° E. Gr.
18°
22°
26°
30°
70°
68°
66°
64°
62°
60°
58°
P.C.
Alkaline eruptive province of Oslo.
Devonian
Scandinavian mountain chain
Sparagmite formation
Raipas formation
Telemark formation
Archæan
Copper ores
Cupreous pyrites
Nickeliferous pyrrhotites with copper
1 Porsanger
2. Repparfjord
3. Porsa
4 Raipas
5 Kåfjord in Alten
6 Kvænangen
7 Vaddas
8 Moskodalen
9 Birtavarre
10 Sjangeli
11 Hopen
12 Sulitjelma
13 Grong
14 Lökken
15 Meraker
16 Kjöli
17 Killingdal
18 Röros
19 Kvikne
20 Röstvangen
21 Foldal
22 Åsoren
23 Årdal
24 Svano
25 Vigsnes and Rödklev
26 Hovin
27 Guldnes
28 Dalane
29 Åmdal
A Ringerike
B Flåt
C Hosanger

Unclassified pre-Cambrian

The copper deposits of Porsanger, in northern Norway, are remarkable for their great extent. Numerous deposits are scattered over an area of about 150 square kilometers, consisting of amphibolites with subordinate belts of quartzite and dolomite. The copper ores, mainly bornite and chalcocite, have partly impregnated the amphibolite itself; partly they occur in veins and veinlets of quartz within this rock. They have not been worked, quantitative figures are not available, and it has not yet been determined at what price for copper they may be considered workable.

A very interesting feature of these deposits is their similarity, both in geology and in mode of ore deposition, to those of the Sjangeli copper mines, 340 kilometers farther southwest, mainly on the Swedish side but partly on the Norwegian side of the frontier. Even in the Telemark formation, in southern Norway, there is a group of copper deposits of the same general character, the Hovin mines.

Raipas formation

The Raipas formation appears in a series of windows below overthrust metamorphic rocks of the mountain chain, separated from them by a distinct thrust plane. This formation, which is much less metamorphosed than the overlying rocks, may be subdivided as follows:

Thrust plane.
Bossekop series: Quartzites, tillitic conglomerates, graywackes, and subordinate slates.
Discordance.
Upper Raipas series: Sandstones.
Lower Raipas series: Slates (partly bituminous), dolomites, pillow lavas, tuffs, and intrusive gabbro-diabases and peridotites.

N. Zenzén has kindly prepared the accompanying map (fig. 92), hitherto unpublished, for this paper. According to him, the copper deposits occur exclusively in the lower Raipas series and are genetically connected with the basic intrusives occurring there, which are metamorphosed mainly to albite-epidote-amphibole rocks. The ores occur partly in veins, partly as metasomatic deposits. The most common deposits are quartz-calcite veins, carrying chalcopyrite and pyrite and mainly occurring within the basic intrusives themselves. The fissures were formed during the folding of the Raipas series, which occurred before the deposition of the Bossekop series.

The main groups of deposits are those of the Kvenangen, Kåfjord, and Raipas mines, formerly extensively worked but now idle. Farther north there are a great number of similar deposits in the district of the Porsa mine. This mine is now in operation and produces a flotation concentrate with 22 percent of copper.

The northernmost deposits in this formation are the Repparfjord deposits, which are of a different type. According to Carstens a thick series of graywackes are here more or less impregnated with bornite and chalcocite for a length of 1.5 to 2 kilometers and a width of 100 meters or less. The copper content seems to range between 1 and 2 percent. Sufficient development work for a more detailed statement has not yet been done.

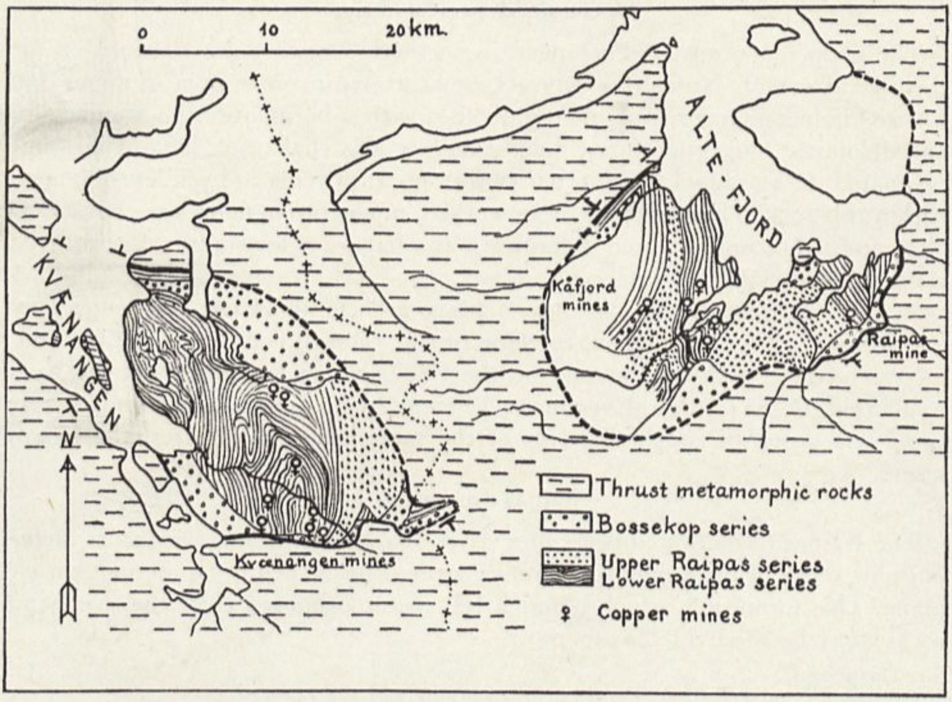


FIGURE 92.—Geologic map of the Kvenangen-Kåfjord district, Norway. (By N. Zenzén.)

The mountain chain

The copper minerals in the Scandinavian mountain chain are to a great extent associated with pyrite. These have been treated in the extensive report "Les réserves mondiales en pyrites," to which the reader is referred for further details. Many deposits, however, contain not pyrite but pyrrhotite, whose sulphur is at present valueless, and therefore have to be treated as pure copper deposits.

In all these deposits the copper mineral is chalcopyrite, locally with subordinate cubanite (chalmersite); bornite and chalcocite are lacking. Sphalerite is generally present, but the content of precious metals is too small to be of economic interest.

The genetic connection of these deposits with the eruptive rocks of the mountain chain was established long ago. They were treated, however, as a unit and considered as intruded magmatic differentiation products in the "igneous" sense. More recent investigations have modified this view in two ways. The deposits are now divided into at least three different but related subgroups, and the magmatic conception has been modified to hydromagmatic and further steps in the apomagmatic direction, as distinguished from the nickeliferous pyrrhotite deposits. The subgroups are as follows:

1. Leksdal type: Fine-grained banded pyrite and pyrrhotite without copper. Biochemical sediments between basaltic (spilitic) lava beds, metamorphosed in the greenstone facies. Source of the sulphur volcanic exhalations.

2. Röros type: Pyrite and pyrrhotite with varying amounts of copper, near gabbroic intrusives, always metamorphosed to saussurite gabbros, amphibolites, or chloritic schists. Precise conditions of ore formation not quite certain.

3. Björkåsen type: Mainly pyrite with quartz; low in copper. Younger than the trondhjemites and similar acidic differentiation products, following the basic intrusions. Ore formation at lower temperature than the Röros type and often accompanied by extensive sericitization.

With these groups might be ranked certain zinc and lead deposits, many of them with copper, of still more apomagmatic character and in places evidently metasomatic. The gabbro-trondhjemite rocks form a comagmatic series, and the sulphidic ores accompanying them are genetically related.

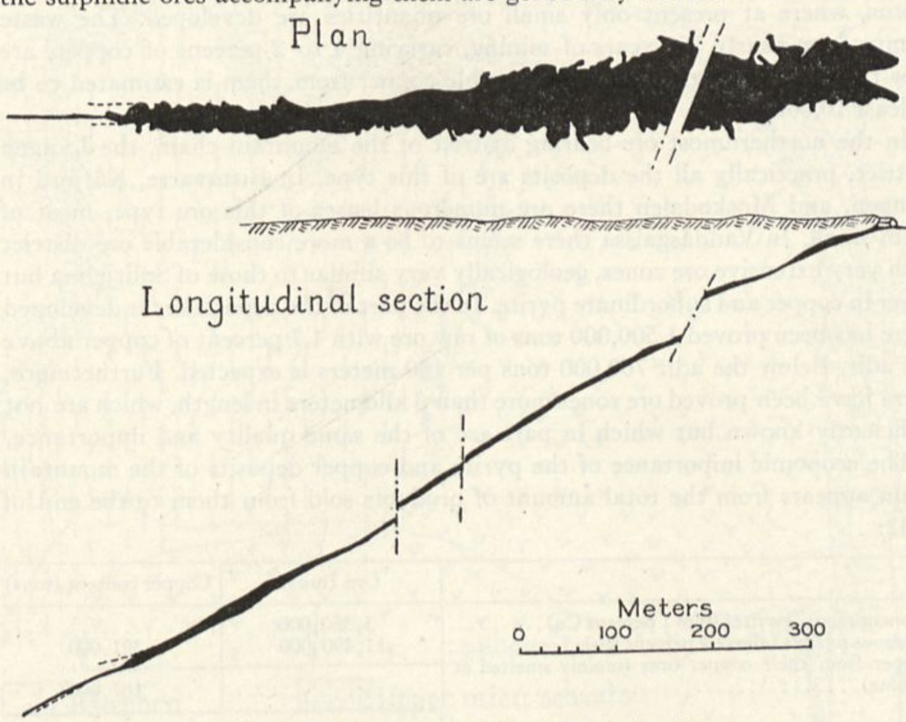


FIGURE 93.—The ore body of the Killingdal mine, Norway.

As copper producers practically only the deposits of the Röros type possess any importance. These deposits were formed during the period of mountain folding, and their form has been influenced by these movements. In consequence they are generally more or less flattened fishlike lenses, with their long dimension parallel to the more or less pronounced axis of folding. Their length is commonly much greater than their width, and the width is generally greater than the thickness. In the most extreme cases, however, they may take the form of pencils. Furthermore, they are generally localized in the rocks that have yielded most easily to mechanical stress and have become more or less schistose, and not in the rocks that are most easily attacked chemically, such as limestones.

Figure 93, which represents the ore body of the Killingdal mine, is a typical example.

Ore deposits of this type are found along the whole length of 1,400 kilometers of the mountain chain, except in the Jotunheimen district of central southern Norway, which is characterized by eruptives of another petrographic province. The main copper-bearing districts, from south to north, are Hardanger, Trondheim, Grong, Sulitjelma, and Lyngen.

The bulk of the copper resources is found in the Lökken, Grong, and Sulitjelma mines. These and the other mines working cupreous pyrites have been described in the monograph on pyrite cited above, and recent statistical data are given elsewhere in this paper.

The nonpyritic pyrrhotite-chalcopyrite deposits of southern Norway are relatively small. The most important ones have been some of the main mines of Röros, where at present only small ore quantities are developed. The waste dumps from nearly 300 years of mining, carrying 1 to 2 percent of copper, are now treated by flotation. The recoverable copper from them is estimated to be at least 10,000 tons.

In the northernmost ore-bearing district of the mountain chain, the Lyngen district, practically all the deposits are of this type. In Birtavarre, Kåfjord in Lyngen, and Moskodalen there are numerous lenses of this ore type, most of them small. In Vaddasgaissa there seems to be a more considerable ore district with very extensive ore zones, geologically very similar to those of Sulitjelma but lower in copper and subordinate pyrite. In the part of the deposit so far developed there has been proved 1,500,000 tons of raw ore with 1.7 percent of copper above the adit. Below the adit 700,000 tons per 100 meters is expected. Furthermore, there have been proved ore zones more than 3 kilometers in length, which are not sufficiently known but which in part are of the same quality and importance.

The economic importance of the pyrite and copper deposits of the mountain chain appears from the total amount of products sold from them to the end of 1932:

	Ore (tons)	Copper content (tons)
"Noncupreous" pyrites (0 to 1 percent Cu)	3,350,000	......
Cupreous pyrites (above 1 percent Cu)	11,490,000	291,000
Copper from their copper ores (mainly smelted at home)	......	167,000
	14,840,000	458,000

In the eruptive rocks of the Jotunheimen district only one group of copper deposits is known—those of the Aardal mines. These deposits are of entirely different type. According to N. Zenzén bornite and chalcopyrite, partly accompanied by titanite and epidote, occur as impregnation deposits and veinlets in an amphibolized gabbro. A nearly related type carries cuprite, metallic copper, and chrysocolla on zeolitized, calcite-bearing fracture zones, which also cut trondhjemitic rocks, younger than the gabbro. Visible gold has been proved on quartz veins.

Oslo district

Near the contacts of the Permian eruptive rocks of the Oslo district and Silurian sediments, rich in lime, there have been developed a great many deposits of typical contact-metamorphic origin. The main metals are iron, zinc, and lead. Copper occurs but has never been of any importance. Quartz veins of the same age have penetrated far into the surrounding Archean. They carry sphalerite, galena, and chalcopyrite, but the copper content is generally subordinate.

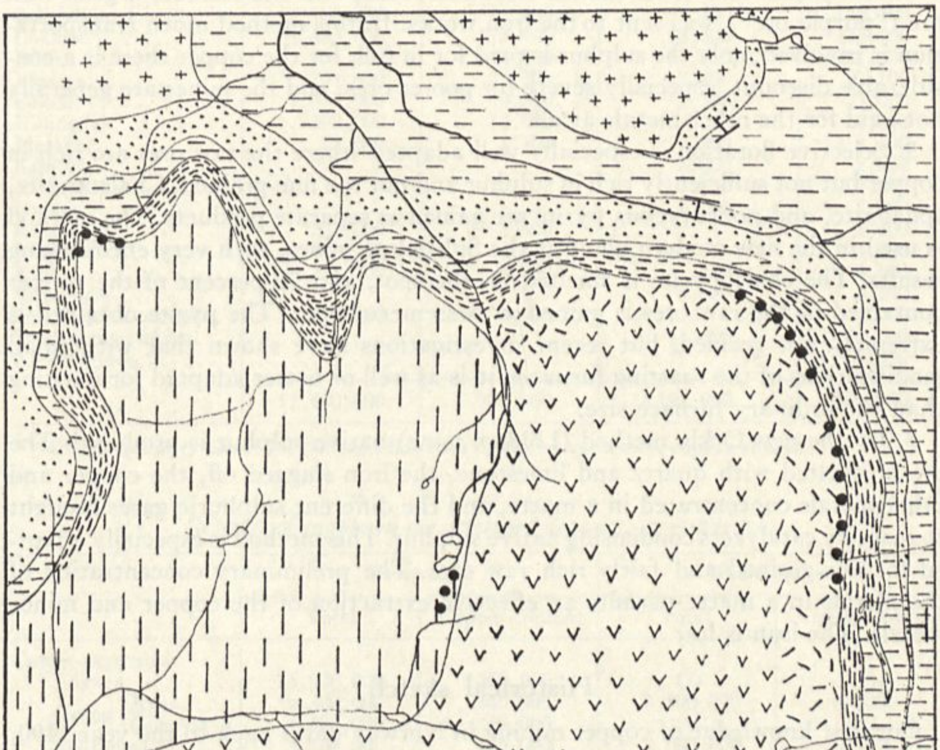


FIGURE 94.—Map showing geology of the Vaddas copper deposits, Norway. (After Thorolf Vogt.)

Technical development

The pure copper ores, raw or concentrated, are for the greater part smelted at home in the ordinary ways.

For the cupreous pyrites the treatment is more complicated, because so widely different substances have to be utilized, and in the later years new courses have been pursued. There are at present three modes of procedure:

1. According to the old method, which is still most used, especially at small mines, the sorted raw ore was simply crushed to "furnace size," or the sulphides were concentrated "en bloc." The product was sent to the sulphur consumer and roasted; the calcined product was sent to the leaching plants, where copper and eventually zinc and other metals were extracted; and the residue, a good iron ore ("purple ore"), was sent to the iron works. In this method much transportation is involved, only the sulphur is paid for in full, for the copper there is a considerable discount, especially severe for poorer ores, and the mines are generally not paid for the other metals at all.

2. Selective flotation is especially well adapted where the raw ores are rich in copper but not sufficiently rich in sulphur and not too fine-grained. Chalcopyrite, sphalerite, and noncupreous pyrite are gained as separate products. The method is used in the new modern plant at the Sulitjelma mines, with very encouraging results. The chalcopyrite is smelted on the spot, and 90 percent of the copper contained in the raw ores is gained as bessemer copper. The pyrite obtained is extremely fine-grained, but recent investigations have shown that with small modifications of the roasting furnaces it is as well or better adapted for roasting than the ordinary furnace size.

3. By the new Orkla method (Lökken mine) native sulphur is produced. The ore is smelted with quartz and limestone, the iron slagged off, the copper and other metals concentrated in a matte, and the different sulphuric gases brought to react by catalyzers condensing native sulphur. This method is especially adapted for fine-grained and fairly rich raw ores. The preliminary concentration of the metals in a matte permits an effective extraction of the copper and minor metals. The iron is lost.

Historical sketch

Our first knowledge of copper mining in Norway dates back to the year 1490, when a small mine was worked in Sandsvær (Samsonberg), near Kongsberg. About 1540 considerable mining operations commenced in the Telemark district, which for a time remained the main copper producer. In 1630 the first copper works in the mountain chain began at Kvikne and Ytteröen. In 1644 Röros was discovered. It remained for a long period the main copper producer of Norway and is still in practically continuous operation. Subsequently many small copper mines were opened in different parts of the country. About 1860 the value of the pyrites was realized, and a new period of more rapid development commenced. The cupreous pyrites, which had hitherto not been workable for copper alone, now offered great economic possibilities and gradually became the main copper producers.

Statistical data

The total production of Norwegian copper mines to the end of 1932 was as follows:

Copper produced from Norwegian mines to end of 1932, in metric tons

	Cupreous pyrite	Copper		
		In cupreous pyrite	From copper ores and concentrates	Total
Sulitjelma	3,130,000	92,400	37,400	129,800
Lökken	4,435,000	111,000	14,400	125,400
Röros	534,000	13,800	87,800	101,600
Vigsnes	791,000	23,700	3,400	27,100
Foldal	1,037,000	19,500	3,500	23,000
Killingdal	693,000	12,000	....	12,000
Meraker	72,000	1,100	7,300	8,400
Aamdal	....	....	8,000	8,000
Kåfjord in Alten	....	....	7,800	7,800
Kvikne	....	....	7,000	7,000
Röstvangen	205,000	5,400	....	5,400
Rödklev	208,000	4,800	....	4,800
Kjöli	228,000	4,350	250	4,600
Birtavarre	....	....	3,500	3,500
Small pyrite mines	157,000	3,000	....	3,000
Small copper mines	....	....	11,600	11,600
Nickel mines	....	....	....	7,000
	11,490,000	291,000	[a] 192,000	490,000

[a] Of this quantity about 165,000 tons has been produced as metallic copper at home.

Reserves of copper in the developed deposits, in metric tons

	Ore in sight		Probable ore	
	Total	Copper content	Total	Copper content
Cupreous pyrites:				
Lökken	14,000,000	350,000	(?)	(?)
Grong {Joma	6,300,000	140,000	2,800,000	60,000
Grong {Gjersvik	1,400,000	30,000	....	....
Sulitjelma	3,100,000	56,000	3,000,000	54,000
Foldal	300,000	4,900	300,000	4,900
Killingdal	150,000	2,600	100,000	1,700
Kjöli	100,000	1,900	150,000	2,900
Rödklev	50,000	1,300	....	....
Copper ores:				
Vaddas	1,500,000	25,300	....	....
Röros	[a] 700,000	7,000	....	5,000?
Aamdal	....	7,000	....	5,000
Nickel ores	1,500,000	13,000	....	....
		639,000		134,000

[a] Waste dumps.

This is the gross content in the ores. The extraction varies for the different ores between 75 and 90 percent. As the large mines, which really count, have the most modern equipment, the average in the future will not be much below 90 percent. Furthermore, the yield from several deposits that offer possibilities cannot be calculated at all, or only in part.

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Production du cuivre dans le Portugal Continental

Par la Direcção Geral de Minas e Serviços Geologicos, Repartição de Minas

Lisboa

Les zones cuivreuses du Portugal continental (fig. 95) ont déjà été décrites par l'ancien Ingénieur Directeur Général des Mines et Services Géologiques, M. Manuel Roldán y Pego.[1] C'est pourquoi nous nous limiterons à ne présenter qu'un bref renseignement sur les altérations qui ont eu lieu pendant la période qui va de 1926, année à laquelle se rapporte la dernière information de M. Roldán y Pego, à 1932, ainsi que d'indiquer les numéros donnés par la Statistique Minière pendant cette même période.

Mine de S. Domingos

La concession de la mine de S. Domingos a été faite à la Companhia Sabina, qui en 1858 fit son affermage à la société anglaise Mason & Barry qui fait présentement son exploitation.

Ses mouvements d'extraction et d'exportation ont obtenu les résultats suivants:

Année	Extraction				Exportation et vente dans le pays			
	Pyrite cuivreuse		Cuivre précipité		Pyrite cuivreuse		Cuivre précipité	
	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)
1926	152,873	1.11	356.000	75.11	138,651 37,363	0.96 .35	468.460	75.11
1927	24,820 145,347	2.15 .82	408.000	73.83	172,663 38,050	.97 .44	302.000	73.83
1928	186,615	.97	362.000	70.76	198,494 5,616	.99 .36	362.000	70.76
1929	224,874	1.05	299.000	72.78	204,855	1.01	299.000	72.78
1930	203,520	1.00	317.887	71.09	207,914	.99	317.887	71.09
1931	200,205	1.05	365.000	73.12	173,128 7,563	1.05 .5	423.937	72.9
1932	159,520	.94 .46	345.780	74.26	158,178	.94 .46	301.737	73.36

Dû au bas prix du marché, l'extraction en 1932 a été réduite à 159,520 tonnes, moins 40,685 que celle de 1931. La quantité de 159,520 tonnes provient de l'exploitation souterraine et du minerai trouvé dans les haldes (1,726 tonnes).

[1] Gisements de pyrites du Portugal: Les réserves mondiales en pyrite, vol. 1, pp. 249–260, XIV Cong. géol. internat. (Espagne, 1926), Madrid, 1927.

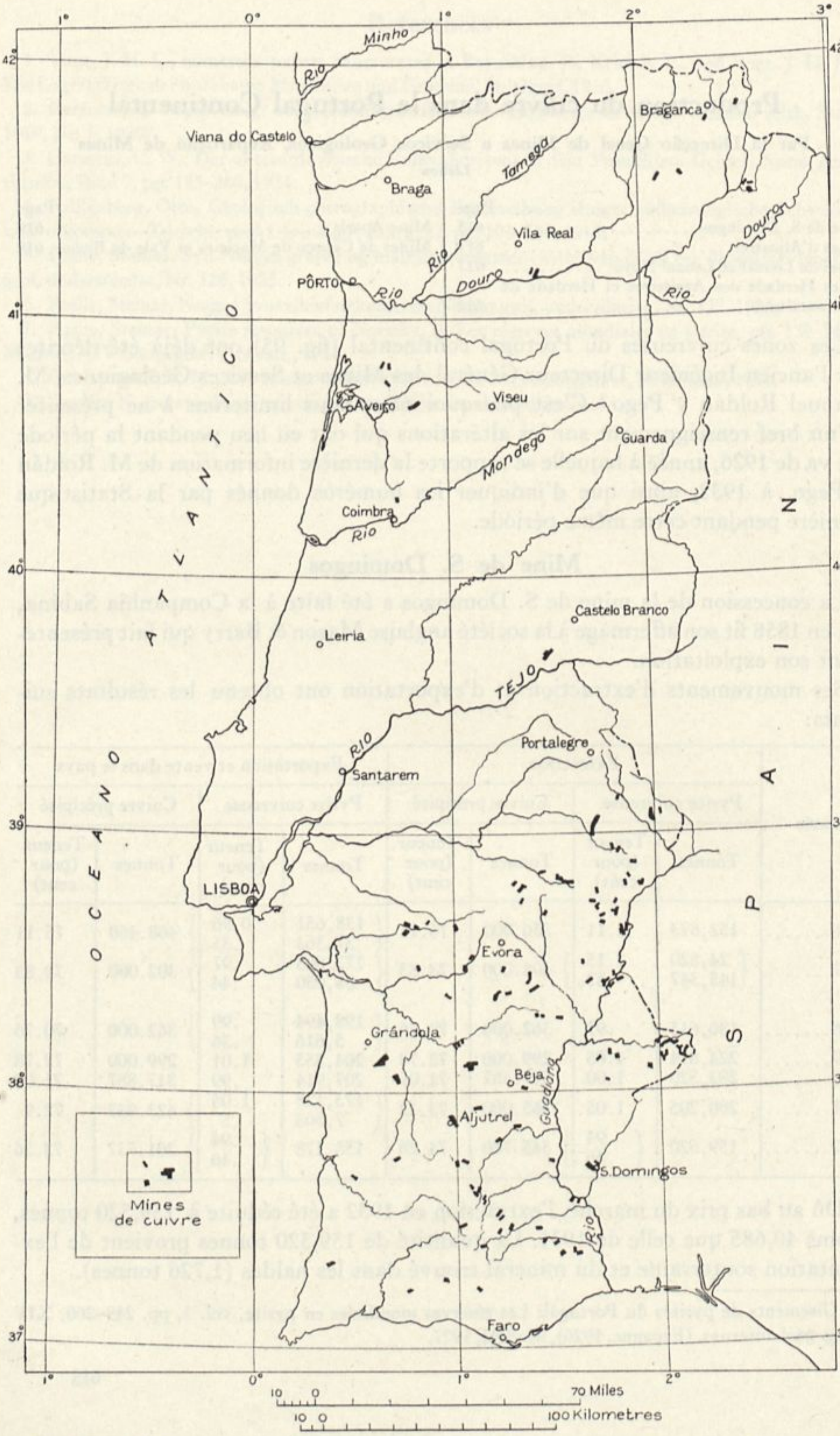

FIGURE 95.—Situation des mines cuivreuses dans le Portugal. (D'après la carte minière de A. Vianna.)

La teneur moyenne en cuivre dans l'année de 1932 a été de 0.94 pour cent contre 1.05 pour cent de l'année précédente.

À cause de la grande crise mondiale, l'exportation du minerai a été seulement de 158,178 tonnes (de minerai), contre 180,691 tonnes en 1931. Ces 158,178 tonnes de minerai comprennaient 156,193 tonnes de minerai cru et 1,985 de minerai lavé sorties du champ de cémentation. La production de cuivre précipité a été de 345.78 tonnes avec la teneur moyenne en cuivre de 74.26 pour cent, contre 365 tonnes en 1931 avec la teneur moyenne de 73.12 pour cent. La production de "cobre fino" a été de 258 tonnes, contre 267 tonnes en 1931.

Les réserves probables sont impossibles à calculer.

Mines d'Aljustrel

Les mines d'Aljustrel sont situées au concêlho (commune) et distrito de Beja et appartiennent à la Société Anonyme Belge des Mines d'Aljustrel. Elles sont formées par deux gisements de pyrite cuivreuse—S. João do Deserto et Algares. (Pour la description géologique, voir Les réserves mondiales en pyrite, vol. 1, p. 254.)

À cause de la crise générale et surtout pour n'avoir pas encore résolu leur problème de transports, ces mines ont vu diminuer de beaucoup leur mouvement d'extraction, comme on peut le constater par le tableau suivant:

Année	Extraction				Exportation et vente dans le pays			
	Pyrite cuivreuse		Cuivre précipité		Pyrite cuivreuse		Cuivre précipité	
	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)	Tonnes	Teneur[a] (pour cent)	Tonnes	Teneur (pour cent)
	5,680	2.5						
1926	23,764	1.2	1,060.000	76.00	26,471	1.0	1,060.000	76.00
	77,251	1.0						
	6,909	2.0					247.000	72.00
1927	54,389	1.2	868.000	75.00 72.00	50,994	1.0		
	100,039	1.0					621.000	75.00
			469.893	78.00			469.893	78.00
1928	152,398	[a]1.0	47.420	66.00	76,730	1.0	47.420	66.00
			347.501	73.00			347.501	73.00
			607.549	73.60			703.750	73.60
1929	151,341	[a]1.0	72.281	64.17	130,822	1.0	72.281	64.17
			510.667	75.00			523.897	75.00
1930	89,679	....	207.552	64.00	138,467	1.0	212.930	64.00
			6.256	87.70			6.380	87.70
1931	108,679	[a]1.0	431.165	72.90	61,435	1.0	447.172	72.90
			144.131	63.66			149.684	63.60
			2.277	85.00				
1932	22,204	[a]1.0	318.046	70.48	80,986	1.0	424,842	60.00 85.00
			60.986	60.30				

[a] Environ.

Mines de Louzal et Louzal Novo

Les mines de Louzal et Louzal Novo, situées au concêlho (commune) de Grandola, distrito de Setubal, appartiennent à la Sociedade das Minas dos Bairros, Ltd[a], et sont affermées à la Société Anonyme Belge des Mines d'Aljustrel. (Voir Les réserves mondiales en pyrite, vol. 1, p. 256.)

Le mouvement d'extraction et d'exportation de ces mines a été le suivant, depuis 1926:

Année	Extraction				Exportation et vente dans le pays			
	Pyrite cuivreuse		Cuivre précipité		Pyrite cuivreuse		Cuivre précipité	
	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)
1926	28,029	<1	36.136	71.5	8,002.000	<1	36.136	71.5
1927	33,707	<1	[a]	....	35,635.000	<1	[a]	....
1928	[b]	....	18.600	73.00	37,061.000	<1	18.600	73.00
1929	[c]	....	5,102.000	75.00	30,132.630	<1	5.102	75.00
1930	[c]	....	10.720 9.276	73.00 52.00	58,578.530	<1	10.720 9.276	73.00 52.00
1931	[b]	....	[a]	....	44,991.000	<1	[a]	....
1932	56,122	<1	[a]	....	43,114.000	<1	[a]	....

[a] Sans production.
[b] La production a été inférieure à la vente.
[c] À peu près le même que la vente.

Dû à la crise du marché des minerais les travaux d'exploitation ont diminué.

Mines Herdade dos Azeiteiros et Herdade de Montalto

La concession des mines Herdade dos Azeiteiros et Herdade de Montalto, situées au concêlho (commune) de Campo Maior, distrito de Portalegre, et de la mine Herdade da Tinoca, située au concêlho (commune) de Arronches, distrito de Portalegre, a été faite à Tinoca & Mont' Alto Mines, Ltd., et ces gisements sont tout-à-fait d'aspect filonien. Dans les mines Herdade de Tinoca et Herdade de Montalto on laisse encore inonder les travaux et on profite des eaux sulfatées qui sont épuisées, pour précipiter le cuivre par le fer. Ainsi on obtient un précipité dont la teneur est comprise entre 60 à 71 pour cent.

À la mine Herdade dos Azeiteiros ont fait des travaux souterrains.

Année	Extraction				Exportation et vente dans le pays			
	Pyrite de fer cuivreuse ou chalcopyrite		Cuivre précipité		Pyrite de fer cuivreuse ou chalcopyrite		Cuivre précipité	
	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)
1926	....	....	289.100	60	....	....	242.100	60
1927	29.95	16	54.000	60	29.950	16	81.800	60
1928	....	....	85.700	60	....	....	73.450	60
1929	....	....	60.750	55	....	....	80.000	55
1930	....	....	95.257	60	....	....	50.000	60
1931	....	....	135.658	55.5	....	....	53.570	55
1932	....	....	71.313	59	....	....	67.92	59

Mine Aparis

La mine Aparis est située au concêlho (commune) de Barrancos, distrito de Beja. Les travaux qui y ont été paralysés pendant 25 mois ont été repris le 15 mai 1928 et après les réparations nécessaires on a procédé aux travaux de recherches et atteint le niveau de 105 mètres. On a constaté l'existence de deux filons qui se croisaient et dont la minéralisation diminuait en profondeur. Les travaux de reconnaissance du gisement ne sont pas encore suffisants pour calculer les réserves.

Le mouvement d'extraction et d'exportation des minerais de cuivre de cette mine a été le suivant:

Année	Extraction		Exportation et vente dans le pays	
	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)
1926	[a]140	4		
1927			[a]94.500	21
1928	[b]90	4.1		
1929	[c]50	27.5		
1930	[c]3,300 [c]80	3.2 27		
1931	[a]852	4.2	[c]90.500	24.8
1932	[a]27	5.2		

[a] Chalcopyrite.
[b] Bornite et malachite.
[c] Chalcopyrite et bornite.

Mines de Cabeço de Macieira et Vale do Bicho

Les mines de Cabeço de Macieira et Vale do Bicho, dont la concession a été faite pour le plomb et le cuivre à la Compagnie das Minas do Vale do Vouga, sont situées dans le concêlho (commune) de Saver do Vouga, distrito de Aveiro. Leurs gisements filoniens sont composés de minerais de cuivre et de galène, mais ils sont plus riches en cuivre dans la concession du Vale do Bicho. Les concessionnaires ont fait des installations de fluctuation pour la séparation du cuivre, mais à cause de la grande crise qui s'est produit dans le marché des métaux, ils ont été forcés de suspendre l'exploitation de ces mines à partir de 1930.

Le mouvement d'extraction et d'exportation de chalcopyrite de ces mines a été depuis 1926 comme suit:

Année	Extraction		Exportation et vente dans le pays	
	Tonnes	Teneur (pour cent)	Tonnes	Teneur (pour cent)
1926	956.814	11	956.814	11
1927	592.897	13	733.399	13
1928	620.000	17	474.400	17
1929	2,345.000	15	2,205.415	15
1930	683.090	14	1,082.480	14

Los yacimientos y la minería del cobre en España

Por el Instituto Geológico y Minero de España

Esquema geológico de España

La península ibérica es un promontorio de gran altitud, superior a la de los demás países de Europa excepto Suiza. En general está inclinada hacia el Atlántico en pendiente suave y regular, hallándose surcado todo el territorio de montañas orientadas de este a oeste como el curso de los ríos que en su última parte tuercen bruscamente hacia el sur. El interior está formado por tierras altas rodeadas de montañas que presentan amplias fosas al este y sur constituidas por las tierras bajas de Aragón y Andalucía, defendidas a su vez por los Pirineos y la cordillera Penibética. En los bordes norte y sur las montañas se hunden en el mar, formándose estrechas fajas de tierra a lo largo del litoral.

El meridiano de Madrid divide a la península en dos porciones casi iguales en extensión superficial pero muy distintas en cuanto a su composición geológica. En la mitad occidental predominan las rocas hipogénicas y las formaciones sedimentarias más antiguas (estrato-cristalino, paleozoico), siendo pequeñas y escasas las manchas secundarias y cuaternarias; mientras que en la oriental, se extienden ampliamente el Mesozoico y el Terciario, y son relativamente exiguas las representaciones de los terrenos antiguos.

La constitución de la península es sencilla. Alrededor de un antiguo macizo individualizado a fines del Carbonífero, se adosan las zonas deprimidas, limitadas en sus bordes exteriores por cadenas de montañas originadas por los plegamientos alpinos.

El macizo primario forma un falso cuadrilátero limitado al norte por la costa desde Finisterre al cabo de Peñas; al este por la falla que se extiende desde el cabo de Torres hasta Salamanca, y después por una línea hacia oriente hasta pasado Segovia, con un entrante por debajo de Toledo y un saliente hasta Alcaraz. El límite sur lo forma otra línea que partiendo de la última ciudad, corre a lo largo de la falla del Guadalquivir, importante línea tectónica próxima al curso de este río en las provincias de Jaén y Córdoba; se aparta luego en la de Sevilla hasta llegar a la desembocadura del Guadiana, y acaba en Portugal en el cabo de San Vicente. Por último, el macizo se halla limitado al oeste por el meridiano que va próximamente desde el mencionado cabo de San Vicente al de Finisterre.

Dos algos lagos terciarios—el de Castilla la Vieja y el de la Nueva—y un golfo marino de la misma edad, bordean respectivamente las concavidades orientales del macizo y el límite sudeste del mismo. Envolviendo a estos lagos y golfo terciarios, existe una arrugada cintura oriental de terrenos secundarios, que forma arco a través de las provincias de Santander, Burgos, Soria, Teruel, Albacete, Jaén y Cádiz, y cuya erección corresponde a la de los Alpes.

Al nordeste del arco secundario se encuentra la fosa terciaria del Ebro, limitada por el Pirineo y la cadena costera catalana. En otro tiempo estuvo ocupada esta depresión por las aguas del mar, pero más tarde, cuando emergió la cordillera catalana, se convirtió en un lago cerrado cuyos depósitos (oligocenos y miocenos) rellenan la hondonada.

Al sur del macizo y de la falla del Guadalquivir, aparece la depresión bética formada en virtud de una serie de transtornos que acumularon los materiales sobre el fondo del estrecho que hasta el Terciario ponía en comunicación el Mediterráneo y el Atlántico. Posteriormente, a causa de los movimientos que produjeron la cordillera Penibética, se redujo a un golfo que fué degenerando hasta convertirse en el valle actual.

Finalmente, en el borde occidental del macizo, se encuentra un conjunto de terrenos secundarios confundidos con los estratos terciarios, cuaternarios y aluviones recientes de los alrededores de la bahía del Tajo, por donde el mar penetraba antiguamente. Estos terrenos forman la orla portuguesa, que es un elemento menos importante que los anteriores.

A los expresados grupos tectónicos hay que añadir como rocas endógenas, los macizos graníticos del noroeste, el central de Sierra de Gredos, los del sudoeste y Extremadura, y los núcleos de las cordilleras Pirenaica y Catalana. Existen además, la gran mancha peridótica de Málaga, una profusión de pórfidos y diabasas en la región sudoeste, abundantes ofitas en los Pirineos, provincias Vascongadas y Levante, y por último basaltos en Cataluña, Almería y Ciudad Real.

Los distritos cupríferos españoles

Muy importantes son los recursos que tiene España de minerales de cobre, pudiendo decirse que hasta ahora dicha riqueza se halla concentrada en la región sudoeste, en una zona paleozoica que partiendo de la parte occidental de la provincia de Sevilla, corre en ancha faja por la de Huelva hasta internarse en Portugal.

La provincia de Huelva lleva la supremacía de la actividad minera, pues en ella radican las explotaciones más importantes. En Sevilla y Badajoz existen minas de cierta categoría, y aparecen además manifestaciones menos importantes en otras provincias españolas.

Huelva

La geología de la región de Huelva, considerada en conjunto, se compone de

1° Un gran anticlinal estrato-cristalino que corresponde al eje de Sierra Morena conocida localmente con el nombre de "Sierra de Aracena."

2° Al sur de esta faja, se adosa otra de sedimentos silurianos y carboníferos sometidos a pliegues hercinianos de dirección N. 60° O., a cuya banda, afectada por intrusiones de rocas hipogénicas, pertenece la zona minera.

3º Un área meridional de formaciones cuaternarias dominantes con un manchón terciario en el contacto sudeste con la faja minera.

4º Al norte del gran anticlinal de la Sierra de Aracena, corre una banda siluriana, y más al norte otra cambriana, hasta los límites con la provincia de Badajoz.

Los yacimientos cupríferos encajan generalmente en el Siluriano o en el Culm, presentándose interestratificados con las rocas sedimentarias o en los contactos de éstas con eruptivas cuyas digitaciones numerosas sirven de hastial a los diferentes minerales o están próximas a ellos y en íntima conexión con su proceso genético.

Los materiales sedimentarios son principalmente pizarras o verdaderas grauwackas, mientras los eruptivos pertenecen en general, al grupo de porfiditas diabásicas, a los pórfidos graníticos y a las sienitas.

La dirección de los yacimientos, en forma de lentejones, es, naturalmente, la herciniana por ser ésta la de la estratificación general de las capas—es decir, próximamente noroeste-sudeste—y el buzamiento a grandes rasgos, siempre norteado.

Hay yacimientos como Río Tinto en que algunas masas han llegado a espesores de 200 metros y no son raros los de 80 metros, considerándose corriente una potencia de 20 a 30 metros. Las corridas son muy variadas. Sin contar las excepcionales del yacimiento de San Dionisio en Río Tinto, son corrientes longitudes de 700 a 800 metros. Algunas de las masas han acuñado en profundidad, pero otras, en cambio, continúan a 500 metros de la superficie como la citada de San Dionisio.

El relleno es de pirita de hierro propiamente dicha, limpia y compacta. El mineral es esencialmente pirita ferrocobriza con 0.5 a 3 por ciento de cobre, 42 a 48 por ciento de azufre, pequeñas impurezas de plomo, zinc y arsénico con cantidades a veces beneficiables de oro y plata, y en determinados yacimientos, de selenio. Únicamente en la zona próxima a Portugal, se acusan minerales complejos, en los que el plomo y el zinc entran por cantidades de 3 por ciento y más.

Mucho se ha discutido la génesis de estos grandiosos yacimientos. Sin embargo, la forma lenticular de las masas, su conexión evidente con los pórfidos y demás rocas endógenas, y los argumentos expuestos en los últimos tiempos para explicar los depósitos análogos de Noruega, dan un gran valor a la teoría de la segregación magmática.

La existencia, en efecto, en regiones semiprofundas, de un magma piritoso, puede originar débiles expansiones lacolíticas por compresión merced a empujes tangenciales. Entonces se insinuaría aquél entre los estratos, produciendo masas lenticulares.

Por otra parte, puede llegarse al mismo resultado mediante un proceso de diferenciación en un magma extendido en forma de lacolitos y sujeto a enfriamiento lento, en cuyo caso, las piritas cristalizarán primero y por gravitación se irán situando en la parte inferior del desbordamiento de la expansión lacolítica. El resto de la roca se consolidará encima, y si posteriormente, el conjunto de los terrenos es afectado por movimientos tectónicos que levanten los estratos y las expansiones lacolíticas, afectarán éstas y las masas de pirita diferenciadas el tipo de grandes diques y lentejones que ofrecen los yacimientos ferrocobrizos de Huelva.

Toda la región ha sufrido una acción continental extremadamente intensa que comenzó quizás con fenómenos de erosión anteriores a la transgresión triásica y ha continuado hasta nuestros días. En una zona tan rica en sulfuros, es evidente que las aguas, después de hacerse vitriólicas, han ejercido una acción enérgica cuyos vestigios se comprueban en las rocas que han sido kaolinizadas y aún reducidas a un esqueleto cuarzoso.

El primer efecto de esta alteración, es la producción de una montera de limonita que llega a veces a 40 metros de espesor, y debajo de ella aparece una zona de cementación cuprífera. Los sulfuros se han oxidado en la superficie al contacto del aire y del agua, y los sulfatos solubles descendieron de nuevo sufriendo una reducción debajo de la zona oxidante del nivel hidrostático y formando zonas ricas intercaladas entre la montera y la parte inferior del yacimiento. Así, deben dirigirse los trabajos de investigación acercándose lo más posible al plano inferior de las aguas con el fin de alcanzar el yacimiento en su parte más rica.

En la región de Huelva, a más de las conocidísimas minas de Río Tinto, Tharsis, La Zarza, Perrunal, Sotiel Coronada, Buitrón, Concepción, Esperanza, etc., existen innumerables yacimientos en trabajos y explotación en gran escala.

He aquí las principales minas con las reservas de mineral calculadas:

Mina	Mineral (toneladas)		Ley media (por ciento de cobre)
	Reconocido	Probable	
Río Tinto	151,306,050	70,000,000	....
Tharsis	56,500,000	76,250,000	0.75
La Zarza	35,000,000	20,000,000	0.50–1
Perrunal	6,000,000	6,000,000	0.50–0.65
Cueva de la Mora	3,047,000	722,000	1–1.20
Nerva	3,000,000	3,000,000	....
Herrerias	2,000,000	5,000,000	....
La Torrera	1,500,000	....	1.39
Concepción	1,400,000	1,000,000	1.10
Buitrón	1,150,000	2,000,000	0.6–1.3
Sotiel Coronada	1,000,000	660,000	0.6–1.5
San Telmo	607,000	704,000	2.75
San Platón	500,000	1,000,000	3–4
Santa Rosa	400,000	100,000	1–1.6
Carpio	335,000	2,800,000	2–8

Sevilla

Al noroeste de la provincia de Sevilla, a 30 kilómetros de la capital y cerca de Aznalcóllar, se encuentra el yacimiento de Silillos y Cuchichón, de formación semejante a los de Huelva. Las rocas que circundan la masa son pizarras y grauwackas, no habiéndose encontrado fósiles. Paralelamente a la dirección de las pizarras, y en las proximidades del mineral, hay asomos de pórfidos cuarcíferos que abundan en casi todo el grupo y están distribuidos en dos cinturones de dirección este-oeste. Entre ambos cinturones se hallan los depósitos de mineral, habiéndose descubierto siete masas. La ley oscila entre 0.4 y 4 por ciento de cobre, y las reservas probables ascienden a 5,000,000 toneladas.

En el mismo término de Aznalcóllar, próximo a dicho pueblo, se halla el yacimiento de la mina La Caridad, que arma en pizarras encajadas entre dos diques de pórfido y se halla cortado por varias fallas con saltos en horizontal, que lo dividen en cuatro zonas. El mineral cobrizo, que ha alcanzado 8 por ciento de cobre, queda limitado a la parte más alta del yacimiento.

Las minas del Castillo de las Guardas, explotadas desde hace muchos años, ofrecen todavía un porvenir del mayor interés. Los minerales alcanzan una ley de 1 por ciento de cobre, y los más cobrizos se hallan de preferencia en la parte oeste del yacimiento. Las reservas actuales alcanzan a 3,500,000 toneladas y las probables a 7,000,000 toneladas.

En Peñaflor del Río aparece otro yacimiento que arma en gneis y micacitas del estrato-cristalino, atravesados en algunos puntos por dioritas. El terreno de la superficie corresponde al Mioceno. El yacimiento está formado por dos masas que corren paralelamente en dirección N. 20° E., con buzamiento de 80° O., presentando ensanchamientos y ramificaciones. A la pirita de hierro, acompañan diferentes sulfuros de cobre con ley media de 2.30 por ciento de cobre, siendo la reserva probable de unas 850,000 toneladas.

Badajoz

Los trabajos practicados en la mina Romanera, en la provincia de Badajoz, han demostrado la existencia de tres masas lenticulares que probablemente habrán de unirse en profundidad. La corrida de la zona mineralizada, tiene cerca de 400 metros, siendo el mineral algo complejo, con proporciones acusadas de zinc y plomo principalmente. El yacimiento arroja un tonelaje reconocido de 200,000 toneladas y otro probable de 800,000, pudiendo estimarse las reservas posibles en 1,000,000 toneladas.

En las concesiones del grupo California-Concordia, situadas en la Dehesa de la Vicaria, término de Calera de León, se perciben tres series de afloramientos; el principal, de 150 metros de longitud y potencia variable de 20 a 30 metros, llama la atención por sus características y está formado por limonita. El yacimiento es de pirita ferrocobriza, pudiendo admitirse como tonelaje probable 500,000 toneladas y como posible 500,000 a 750,000 toneladas.

El yacimiento de Las Merlizas, del término de Cheles junto a la frontera portuguesa, consiste en un filón casi vertical, de dirección norte-sur, con un recorrido de 500 metros, que encaja en las pizarras silurianas y tiene una potencia de 1.5 a 2 metros. Está compuesto de hidróxidos de hierro en los afloramientos e hidrocarbonatos de cobre en la zona de cementación que se encuentra de 20 a 40 metros bajo la superficie.

Cáceres

En la provincia de Cáceres se encuentran yacimientos cupríferos en la gran mancha siluriana de Guadalupe y zonas cambrianas colindantes. A 2 kilómetros al oeste de la referida villa, existe un filón cuarzoso, de dirección N. 35° E., encajado en pizarras amarillentas, que ofrece pequeñas cantidades de pirita cobriza y cobre gris. Las mejores muestras han dado 17 por ciento de cobre.

También en Plasenzuela, a 30 kilómetros de Cáceres, hay filones explotados desde muy antiguo, que encajan en las pizarras del Cambriano. La metalización principal es en plomo, plata y zinc, pero se presenta el cobre como elemento accesorio.

Córdoba

En el cerro Muriano, junto al kilómetro 24 de la carretera de Córdoba a Villaharta, aparecen varios filones cobrizos que se explotaron en gran parte por los romanos. El principal, que contiene cuarzo y pirita ferrocobriza, posee 1 metro de espesor y 4 por ciento de metalización, habiendo sido trabajado últimamente por varias sociedades inglesas que no hace mucho dieron por terminadas sus labores.

Otro filón de cuarzo cuprífero se encuentra en el kilómetro 17 de la misma carretera, prolongándose hasta las orillas del Guadiato, cerca del cortijo del Quejigo.

Jaén

Por los términos de Andújar, Villanueva de la Reina y Baños de la Encina, en la provincia de Jaén, se extiende una zona cuprífera de interés. Los filones arman en el granito y las pizarras paleozoicas, siendo el más importante el llamado "de los Escoriales," de 17 kilómetros de longitud, con rumbo N. 80° E. y potencia media de 2 a 3 metros. El relleno en la parte central es de calcosina, calcopirita y carbonatos de cobre, acompañadas de hierro y siderosa, a cuyos elementos, se suman el cuarzo y el granito descompuesto. Algunas de las menas han alcanzado una ley de 32 por ciento de cobre.

En diversos parajes de esta zona, existen indicios que atestiguan el beneficio intenso del cobre en épocas remotas.

Granada

Por las vertientes septentrionales de la Sierra Nevada, en la provincia de Granada, cortan a las micacitas del Marquesado de Cenet y Güejar-Sierra tres sistemas de filones cupríferos presentando los principales fuerte buzamiento al oeste-sudoeste. Existen más de 20 por las lomas de San Juan y del Lanchar, variando sus espesores entre 0.40 y 2.25 metros. El relleno es de composición muy compleja. En la mina Trueno, a orillas del Genil, el mineral alcanza en profundidad una ley en plata que llega por término medio a 600 gramas por tonelada, ley que asciende al doble en los términos inmediatos de Aldeire, Lanteira y Baza.

En la carretera de Granada a Guadix, a 25 kilómetros de la capital, radican las minas de El Molinillo que, además de un lecho de galena muy argentífera, encierran un yacimiento sedimentario de pirita y carbonatos de cobre, que arma en terreno triásico de facies lacustre. En un nivel estratigráfico superior, se ven capas de margas y areniscas con tallos vegetales fosilizados en parte en calcosina, y se hallen también nódulos esféricos de cobre vítreo, debidos probablemente a la concentración del mineral alrededor de grupos orgánicos.

Murcia

En Santomera, cerca del límite de la provincia de Murcia con la de Alicante, en el valle del Segura, aparece un yacimiento de cobre de cierta importancia, constituido por un sedimento de origen químico del tipo de Perm y Mansfeld. Su edad corresponde a la fase herciniana y parece ser la última manifestación de una serie de fenómenos semejantes multiplicados en esa época. La formación encierra pirita de cobre, cobres rojos, hidrocarbonatos de cobre y a veces oro nativo, presentándose en la caliza del Keuper surcada por coladas de rocas hipogénicas básicas (meláfidos, diabasas) en indudable conexión con la génesis del yacimiento.

En la Sierra de Cartagena, desde Portman hasta cerca de Escombreras, los minerales cobrizos se ofrecen en venillas y pequeñas bolsadas como substancias accidentales de los yacimientos plumbo-argentíferos. Los más importantes se han presentado en las pizarras negruzcas que alternan con calizas pizarreñas de las Umbrias de Carreteros, mezclándose con la galena y el óxido de hierro, el cobre gris, la pirita de cobre y los carbonatos. Estos yacimientos, con 50° a 80° de inclinación al norte y potencia variable de 0.28 a 1.0 metro, han esterilizado a pequeña profundidad.

Baleares

Intercalados en las capas de arenisca del Trias inferior, se presentan en Menorca varios yacimientos cobrizos distribuidos en una comarca que ocupa dentro de la isla unos 28 kilómetros de longitud. El paraje mejor reconocido, se halla en la región central, entre Mercadal y el monte Toro. El banco metalífero, de composición bastante compleja y naturaleza distinta de los que le sirven de caja, es una marga magnesiana de color gris que contrasta con el rojo de las rocas en que se halla interpuesta. El espesor varía entre 0.40 y 1.80 metros.

El mineral de cobre se presenta en el citado banco impregnando el lignito contenido dentro de la marga, de suerte que los vegetales que originaron el carbón están fosilizados por la calcosina. Esta misma especie, se acumula también alrededor de las masas carbonosas impregnando la marga en la proximidad de aquéllas; además se hallan dentro de la roca algunos nódulos de calcosina pura. El contenido de los minerales oscila entre 3 y 35 por ciento de cobre.

Cataluña

En la provincia de Gerona, asoma un filón cobrizo en el pórfido del cerro de Montdevá que aparece en el contacto del granito con las rocas detríticas del Trias inferior. Dicho filón, tiene una dirección N. 35° O. e inclinación media de 35° ENE., hallándose el mineral constituido por calcosina, siderosa, pirita, algo de baritina y cuarzo, con una ley de 31 a 32 por ciento de cobre.

En el valle de Ribas se encuentra la pirita cobriza acompañando a los minerales de mispickel, pero en algunos puntos aparece como mena explotable. Las minas de esta zona, demuestran que ha existido una concentración de sulfuro en la que los minerales vienen a alcanzar leyes de 8 a 12 por ciento de cobre.

En Caralps existe un filón de cuarzo con calcosina y malaquita, que encierra 11 por ciento de cobre y en el valle de Rigart, se encuentra cobre gris con 35 por ciento de cobre y 0.185 de plata.

En Lérida, cerca de Os de Civis y de los límites de Andorra se han observado afloramientos de calcosina con 29 a 30 por ciento de cobre entre las pizarras primarias. Estos afloramientos continúan por la Sierra de Matellá hasta la de

Cuflens, sin que pueda concluirse nada sobre la importancia del yacimiento por no haberse efectuado reconocimientos serios.

En el término de Alforja, la pirita ferrocobriza acompañada de cuarzo, arma en las pizarras primarias formando vetas. No están estudiados tampoco estos yacimientos, que aparecen muy irregulares.

Aragón

La formación cuprífera más interesante de Zaragoza, la constituyen las areniscas de Sos y Biel, que llegan hasta el nordeste de la provincia en los ayuntamientos de Murillo, Santa Eulalia de Gállego y Ardisa. Se presentan hasta ocho bancos de molasas impregnadas de calcosina con cobre nativo, óxido y carbonatos de cobre, cuyos bancos tienen una potencia comprendida entre 1.5 y 3 metros con longitudes en los afloramientos superiores a 70 metros. La ley media de las muestras es superior a 4 por ciento de cobre. Aunque no existen elementos para efectuar la cubicación del mineral de esta zona, que es muy extensa, no es aventurado suponer que la cifra sea muy elevada.

En la mina Mensula del término de Calcena, que se halla en pizarras y areniscas triásicas, aparecen tres filones de hasta 0.70 metro de potencia, en que el cobre gris, con una ley de 8 onzas de plata por quintal, se asocia a la galena con ganga de cuarzo, un poco de baritina y siderosa.

En la provincia de Huesca continúan las manifestaciones cupríferas sedimentarias de Zaragoza, presentándose en los términos de Labata, Santa Eulalia la Mayor, Barluenga y Ayerbe. Por tratarse de una formación en que los bancos de arenisca han recibido impregnaciones locales de muy distinta riqueza, se encuentran en otros parajes indicaciones análogas, habiéndose recogido muestras con metalizaciones interesantes.

Navarra

Las areniscas cupríferas de Aragón, siguen en Navarra alternando con margas oligocenas impregnadas de carbonatos de cobre. El porcentaje general, parece aquí demasiado reducido para una explotación.

La mina La Amistad explota unos filones en dirección norte-sur con buzamiento de 60° E., que arman en las pizarras hulleras del norte de Vera. El mineral es rubio, y más abajo se presentó el carbonato de hierro con algunas vetas de pirita cobriza.

En la concesión San Luis, de Yanci, las piritas de cobre que arman también en las pizarras hulleras, tienen una ley media de 3 por ciento de cobre después de concentradas.

Provincias Vascongadas

En Iturrigorri, término de Abando, hoy Bilbao, se reconoció un filón de cuarzo y siderosa con piritas de hierro y cobre. Con dirección N. 56° W. e inclinación media de 50° SSO., corta las calizas urgoaptenses prolongándose a través de las areniscas y psamitas inferiores a ellas. En la superficie ofrecía una potencia de 6 a 8 metros, y dentro de él, aparecía una veta de hierro y cobre, de 1 metro de espesor que estrechó en profundidad.

En otra mina del término de la anteiglesia de Aspe, cerca de la Peña de Ambota, existe entre las rocas cenomanenses un filón-capa de siderosa, con piritas de hierro y cobre, cuya potencia es de 0.60 metro y la metalización escasa.

Hace tiempo se explotaron en las cercanías de Villarreal (Alava) algunos filones y vetillas de pirita con 11 por ciento de cobre. Dichos filones, con dirección noroeste-sudeste e inclinación de 60°–70° NO., arman en las areniscas y margas del Cretáceo, presentándose en la superficie bien metalizados aunque empobrecieron rápidamente en profundidad.

Castilla la Vieja

Los yacimientos de cobre reconocidos en Santander, se hallan a 10 kilómetros de Reinosa y arman en las areniscas triásicas de Soto. El filón explotado, de dirección S. 65° E., y buzamiento de 80° SSO., es de pirita con 6 por ciento de cobre y ganga cuarzosa.

La arenisca deleznable del Cenomanense, forma en Huidobro (Burgos) un anticlinal en cuyo flanco occidental se presenta impregnada de malaquita y azurita. El porcentaje es de 0.20 a 0.75 por ciento de cobre y en algunos bancos pasa del 1 por ciento debido a la presencia de la pirita.

En Logroño aparecen minerales cobrizos en el Siluriano y el Wealdense. En el primero existen vetas y filones de cuarzo que atraviesan las pizarras o las cuarcitas, y en el segundo se manifiestan impregnando las areniscas de la división inferior y acompañando a la galena de algunos filones que atraviesan los estratos calizos que cubren a las areniscas. También el terreno triásico ofrece en algunas localidades indicios de minerales cobrizos.

Cerca de Borovia (Soria), en la orilla izquierda del río Mambles, existe un filón de cuarzo que corta verticalmente las capas silurianas y en el que aparecen algunas muestras de pirita y carbonato de cobre. También en la ladera meridional del monte de Teranzo aparecen indicios que hacen sospechar la existencia de otro filón análogo.

En el cerro de los Almadenes, próximo al pueblo de Otero de Herreros de la provincia de Segovia, hay dos filones muy potentes, con importantes manifestaciones de mineral de cobre, que fueron objeto de intensa explotación en la época romana. Tales filones, con dirección N. 25° O. e inclinación de 45° O., se encuentran en la zona de tránsito del granito al gneis. Al este del pueblo y en el granito propiamente dicho, aparecen otros dos completamente independientes de los anteriores, que ofrecen también manifestaciones cuprosas.

Castilla la Nueva

En la Sierra de Guadarrama, se han observado diversas manifestaciones cupríferas, apareciendo en Colmenarejo un yacimiento en rosario formado por calcopirita pura. También en Garganta de los Montes, en el valle del Lozoya, se han reconocido algunos filones de la misma substancia que arman en el gneis y ofrecen una ley de 25 por ciento de cobre que disminuye rápidamente en profundidad. No existen investigaciones suficientes para efectuar una cubicación.

En la provincia de Guadalajara, se han explotado pequeñas minas de pirita de cobre, situadas en las pizarras silurianas de Molina de Aragón, y en la concesión

Ave María del término de Checa, aparece igualmente la calcopirita en un filón de más de 1 metro de potencia.

León

Al norte de Villamanín, se han hallado en la caliza carbonífera algunas acumulaciones de minerales de cobre, niquel y cobalto, que fueron explotados en las minas La Profunda y La Providencia. Las vetas de sulfuros en la caliza y dolomía, dieron lugar a un stockwerk con árboles de metalización que originaría la gran bolsada explotada. En las escombreras antiguas quedan las posibles reservas de cobre que, evaluadas en conjunto, consistirán en unas 3,000 toneladas de mineral con 3 a 4 por ciento de cobre.

Galicia

La mina más importante en Galicia es la llamada "Porvenir," que se halla en La Barquera, a 35 kilómetros de Ferrol (provincia de Coruña) en la cual, el yacimiento forma una masa lenticular de dirección nordeste-sudoeste, incluida entre las pizarras cloríticas arcaicas, con potencia de 0.30 a 1.50 metros. Pueden calcularse como seguras 3,000 toneladas de mineral de 8 a 12 por ciento de cobre, y quizá 15,000 a 20,000 toneladas probables de la misma clase. En Arca, aparece otro yacimiento de roca serpentinosa con calcopirita en la proximidad de las masas eruptivas antiguas (dioritas?).

En Lugo abundan las manifestaciones cobrizas en los ayuntamientos de Becerreá, Cervantes, Nogales y Navia de Luarna, siendo la forma principal la de filones de cuarzo con sulfuros dobles de hierro y cobre, de potencia y contenido muy variables.

Por último, en Mondoñedo hay una caliza cambriana con pirita de cobre, que se prolonga hasta Villanueva de Lorenzana, habiendo demostrado las labores una disposición nodular.

Tecnología de la producción

La minería del cobre se halla circunscrita actualmente a las provincias de Huelva y Sevilla, la primera de las cuales, por la excepcional riqueza de sus yacimientos, ha atraído la atención de fuertes capitales extranjeros que han creado importantes explotaciones. Figura a la cabeza de estas empresas la de Río Tinto, que contribuye por sí sola al 60 a 70 por ciento de la producción total, y siguen en importancia The Tharsis Sulphur & Copper Mines, que explota La Zarza, Sierra Bullones y Almagrera; The United Alkali, con sus minas Concepción, Poderosa, Tinto, Sotiel y Buitrón; la Société française des pyrites de Huelva, con Perrunal, El Lomero y Poyatos; la Société de San Gobain, con Cabezas del Pasto y Herrerías; The Huelva Copper & Sulphur Mines, con Cueva de la Mora y otras; The Peña Copper Mines, con Peña de Hierro; la Compagnie des mines de cuivre de San Platon; la Société des mines de cuivre de Campanario y The San Miguel Copper Mines. También algunas empresas españolas como la Hispalense, la Unión de Explosivos e los Hijos de Vázquez López sostienen otras explotaciones.

Hoy día trabajan unas 15 minas de cobre y pirita ferrocobriza, explotándose a roza abierta y en labores subterráneas por el sistema de huecos y pilares, por labores de través en columnas verticales con rellenos del exterior, o según fajas horizontales ascendentes con rellenos completos.

En Río Tinto, la explotación a cielo abierto, que es una de las mayores de este género que existen, ha requerido costosísimas labores cuyo importe ha sido, sin embargo, amortizado. Se ejecuta por seis pisos de bancos de 16 a 20 metros de altura, haciéndose el arranque con pequeños y grandes barrenos, y en ocasiones mediante voladuras que han llegado a producir hasta 30,000 toneladas. Se emplean perforadoras mecánicas para abrir barrenos de 18 y 20 metros cuya explosión quebranta la roca de modo que puede ser cargada por excavadoras que hacen un desmonte de 1,000 metros cúbicos al día.

Por los bancos circulan los vagones para el transporte del mineral, arrastrados por locomotoras. Algunos túneles permiten a los trenes salir del plano de los diferentes bancos de la excavación e ir a empalmar con la línea férrea.

El total de la población obrera ocupada en los trabajos de las minas, asciende a 12,600 almas, y existen también 6 motores de explosión, 72 máquinas de vapor y 218 eléctricas que suman una fuerza de 23,000 kilovatios.

Con estos elementos, se ha logrado en 1931 una producción de 539,913 toneladas de mineral de cobre, con aumento de 36,000 toneladas en relación al año anterior, y 2,571,786 toneladas de pirita ferrocobriza, destacando por su producción, Río Tinto, La Zarza, Peña de Hierro y Tharsis.

Las piritas son, en general, fácilmente sulfatizables; algunos minerales, ricos y cuarzosos, se funden en la localidad; las menas corrientes con 1.50 a 3 por ciento de cobre, se exportan en crudo, pero la inmensa mayoría de la producción, se trata por oxidación natural, lavado y cementación, fundiéndose gran parte de la "cáscara" en España, exportándose lo restante y haciéndolo también con la pirita lavada salvo las cantidades consumidas en el país para la fabricación de ácido y superfosfatos.

El transporte del elevado tonelaje producido en la región ha exigido la construcción de varios ferrocarriles mineros. El más importante es el de Río Tinto (85 kilómetros) que une las minas con el muelle de embarque de la capital, y son asimismo de gran tráfico los de Zalamea a San Juan del Puerto (57 kilómetros), propiedad de "The United Alkali," y el de Tharsis a Huelva (46 kilómetros) de la compañía The Tharsis Copper.

A este movimiento industrial, responde ampliamente el puerto de Huelva (el segundo de España por su tráfico) con un desarrollo longitudinal de 16 kilómetros, 700 metros de anchura en bajamar y una superficie navegable para grandes buques, de 980 hectáreas. Para las operaciones de embarque, hay 37 depósitos con sus grúas eléctricas y vías férreas, que ocupan 125 metros cuadrados y tienen capacidad para 400,000 toneladas.

En el año 1931, se han exportado 510,982 toneladas de minerales cobrizos con un valor de 10,723,935 pesetas oro, y 12,676 toneladas de cáscara de cobre, cuyo valor asciende a 8,616,240 pesetas oro.

Esbozo histórico de la minería

En España, el cobre, como todas las riquezas contenidas en el subsuelo, es conocido y viene explotándose desde los tiempos más remotos. Los objetos de época poco posterior a la edad de piedra, encontrados en Río Tinto, Cerro Muriano (Córdoba) y el Aramo (Asturias) hacen presumir que dicho metal fué explotado en las edades prehistóricas por una raza análoga a la de Crô-Magnon.

En el siglo 10 anterior a nuestra era, los fenicios crearon en Tharsis un centro industrial de importancia, y durante la dominación griega, adquirió gran desarrollo la fabricación del bronce, fundándose en la región tartesiana varios centros mineros y metalúrgicos.

La época de la dominación cartaginesa no fué apropiada para el desarrollo de la industria, pero en cambio, los romanos, inspirándose en las costumbres helénicas, dieron gran impulso a la minería del cobre. En aquellos días tenían celebridad las minas de Río Tinto, las del Mons Marianus en Córdoba, las de Cotinae y las de Galicia, calculándose que en dicha época se arrancaron 30,000,000 toneladas de mineral. No debió ser despreciable tampoco la metalurgía de entonces, pues los hornos empleados para el beneficio de las menas cupríferas, recuerdan los modernos de reverbero, y la baja ley en cobre, como la limpieza de las escorias, ponen de relieve la habilidad de los fundidores.

La irrupción en el siglo 5 de los germanos, concluyó con las grandes empresas de la minería, y durante la invasión árabe fué escaso el laboreo de nuestros veneros siquiera se trabajasen algunos en determinadas comarcas. El descubrimiento de América, donde tan abundante era la riqueza mineral, hizo desdeñar también la explotación de las minas españolas.

Al finalizar el siglo 17, era poco brillante la situación de nuestra industria; el Estado beneficiaba los yacimientos de Río Tinto y algunos particulares trabajaban con dificultad algunos veneros de cobre, acabando la desastrosa guerra de sucesión con tan escasas manifestaciones industriales.

En 1786 pudo conocerse oficialmente el estado de la minería en España, apareciendo en aquella fecha, en plena producción, 36 minas de cobre en diversas provincias.

Nueva paralización de la minería produjo la guerra de la independencia, pero al terminar, se dictaron varias medidas para favorecer el laboreo y, como consecuencia, volvió a renacer y a divulgarse la fama de nuestras explotaciones. Capitales nacionales y extranjeros tomaron parte en la regeneración de las minas romanas y la iniciativa particular extendió las explotaciones a los diversos yacimientos que hoy conocemos. Con capital francés se comenzaron los trabajos en Tharsis y La Zarza y llegó a crearse un activo comercio con el extranjero que extendió el nombre de Huelva por todo el mundo.

Las minas de Río Tinto que explotaba el Estado, fueron arrendadas a una empresa en 1829, para volver a trabajarse por la Administración 20 años más tarde. Posteriormente y ante las pocas utilidades que se obtenían, hubo diversos intentos de venta hasta que por fin, en 1873, se adjudicaron definitivamente a la casa Matheson y Cia de Londres, que dió un gran desarrollo a los trabajos de explotación, imprimiendo a las minas la marcha que siguen en la actualidad.

Datos estadísticos

Durante algún tiempo ha sido España el primer país entre los productores de cobre del mundo, y aunque superada en la actualidad por otras naciones, representa todavía un papel preponderante en el mercado de este metal.

La producción de piritas ferrocobrizas en el último decenio, según la Estadística formada por el Consejo de Minería, ha sido la siguiente:

Año	Número de minas	Producción (toneladas)	Valor total (pesetas)
1922	43	1,871,509	36,059,356
1923	36	2,163,554	41,070,841
1924	36	1,615,233	42,476,196
1925	49	3,354,200	62,450,502
1926	48	3,650,391	50,825,379
1927	51	3,602,870	48,983,385
1928	51	3,618,691	52,922,857
1929	51	3,861,921	59,975,911
1930	49	3,396,755	67,318,323
1931	15	2,571,786	59,781,913

Durante el mismo período la producción de minerales de cobre ha sido:

Año	Número de minas	Producción (toneladas)	Valor total (pesetas)
1922	12	183,618	1,863,146
1923	12	255,866	8,883,068
1924	11	283,866	12,287,905
1925	7	327,282	14,594,811
1926	2	286,642	7,260,641
1927	2	380,983	9,189,309
1928	3	353,156	10,369,079
1929	3	408,260	12,564,471
1930	6	506,818	12,796,901
1931	3	539,913	13,389,635

La producción de cobre metálico, en cambio, ocupa un lugar más secundario, como puede advertirse por las siguientes cifras:

Año	Cáscara (kilogramos)	Blister (kilogramos)	Electrolítico (kilogramos)
1922	15,524,000	8,015,000	2,000,000
1923	32,080,000	10,126,000	3,060,000
1924	19,749,000	13,297,000	3,300,000
1925	18,111,434	17,224,000	4,074,000
1926	24,399,979	18,101,664	5,823,087
1927	27,986,192	20,241,893	8,446,829
1928	25,488,598	16,840,000	10,917,616
1929	24,898,159	17,032,058	11,423,332
1930	22,961,280	14,850,000	8,145,568
1931	21,509,658	17,751,000	7,982,818

El valor total de la producción de cobre ha sido como sigue:

	Pesetas		Pesetas
1922	34,915,337	1927	93,391,232
1923	60,639,678	1928	93,418,481
1924	66,394,511	1929	125,074,174
1925	69,894,207	1930	74,041,597
1926	84,240,477	1931	57,522,858

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The cupriferous pyrite ores of Huelva, Spain—a tectonic sketch

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Introduction

The cupriferous pyrites with other metallic sulphides of the Sierra Morena, northwest of Sevilla, especially of the district of Huelva, are by far the largest sulphide ore deposits in the world. The annual shipment of pyrite, during periods of normal conditions, surpassed 3,000,000 tons, and this amount could be easily multiplied on demand. On account of their content of copper and gold, these ores have been worked since the time of the Tarthesians and the Phoenicians. Temporarily abandoned, the Rio Tinto mine during the 19th century became one of the famous copper mines of the world. But notwithstanding a period of over 3,000 years of mining, numerous vast deposits are still lying idle on the rolling hills under the natural condition of surface weathering.

Many descriptions of these famous mines have been published, and numerous theories have been expressed to explain such remarkable concentrations of ore. Ample information is given in the Compte rendu of the International Geological Congress at Madrid in 1926, during which an official excursion was guided by Spanish geologists to the Rio Tinto mine and its surroundings.

The idea of a sedimentary origin (Klockmann) having been abandoned, the discussion hinged especially on the question of hydrothermal replacement (metasomatic) or magmatic origin. Broughton Edge (1), in his excellent description, arrived at the conclusion of magmatic origin, but Bateman (2), from evidence furnished by his microscopic studies, accepted the metasomatic theory.

In my opinion, there is no question that to a certain extent and especially along the boundaries of the great ore bodies, replacement, as a secondary phenomenon, has occurred. But laboratory investigation cannot replace tectonic work. Also it is necessary to study numerous localities, for each one shows its peculiarity and may throw new light on the question of origin. This is what Broughton Edge has done, having studied some 30 or 40 ore bodies during several years.

Yet there seems to remain a great gap in the literature which makes it impossible for an outsider to arrive at a proper judgment—the lack of tectonic illustrations. In tectonics words are never able to serve as a substitute for illustrations, and even a bad sketch seems to be better than none. I think, therefore, that tectonic illustrations of some of these huge sulphide ore bodies of Spain, accompanied by the necessary descriptions, may be welcome.

The observations presented in this paper were made in February and March, 1932. Special thanks are expressed to the direction of the Rio Tinto Co., Ltd., for the unusual permission to enter even the underground works; to the excellent geologist of that company, Dr. David Williams; and to the director of the mine of San Telmo, Mr. J. B. Richardson.

Tectonic position of the ore-bearing region of Huelva

Sierra Morena

The region of the famous cupriferous pyrite deposits belongs to the western extension of the Sierra Morena and has a length of about 250 kilometers and a width of 40 to 60 kilometers. It crosses the western frontier of Spain at the Rio Guadiana.

The westerly to west-southwesterly trend of the Sierra Morena is at an angle of 30° to 50° with the general northwesterly to westerly strike of the old formations and seems to be caused by young epeirogenic uplift and relative downthrow of the vast valley of the Guadalquivir along the flexure or faults on its northern border (3). It is a region of rolling hills, of a semimature peneplain which, as a result of upward movement, has recently become gently dissected by river erosion.

In the region north of Sevilla the hills reach an altitude of 600 to 1,000 meters, but they decline toward the west, so that at Rio Tinto they rise only to about 500 meters; in the region from Tharsis to Paimogo, 200 to 400 meters; and west of the Rio Chanza, in Portugal, they hardly exceed 100 meters above sea level (Santo Domingo).

According to the Spanish geologists (4), the sedimentary formations are mica schists of pre-Cambrian and Cambrian age, schists with quartzites of Silurian age, and black and purple slates of Devonian to lower Carboniferous age. It is difficult to trace the boundaries on account of deformation and lack of fossils. These formations are erected and compressed, generally standing vertical or dipping steeply toward the north or northeast, and only exceptionally dipping toward the south.

Igneous intrusives

The sedimentary formations are intruded by igneous bodies, of which the most abundant are quartz porphyries of Paleozoic age. The diabases are less abundant and probably younger, although Paleozoic also. Even the porphyries are somewhat difficult to distinguish from the sedimentary rocks. Indeed, the quartz porphyries are in many places so much compressed that they weather like schists, and where they are decomposed or attacked by sulphuric acid they may be confounded with arenaceous sedimentary formations.

The region of the cupriferous pyrite bodies coincides in a striking way with that in which the innumerable bodies of quartz porphyry intrude the old sedimentary formations (3), although the ores are not directly confined to these porphyries. As remarked by earlier writers, the pyrite bodies may occur at the boundary of porphyry and slate, within the porphyry, or within the slate. But they are unknown in the vast region of Carboniferous slate in southern Portugal west of Huelva, where no porphyry is found.

On the other hand, in some regions with quartz porphyries, especially at Tharsis and farther west, the sulphide ore bodies and their gossans are so astonishingly numerous that the geologist, at first view, might question whether they are not magmatic offshoots of an immense batholith of sulphide ore underneath. Indeed, it would be difficult in certain regions to indicate a location for a pit that would not encounter pyritic ore.

If we consider not only the exposed deposits, but also the numerous gossans which are still untouched over vast territories and indicate pyritic bodies underneath, the amount of 2,000,000,000 tons of cupriferous pyrite in the whole region, within a depth of about 400 meters, seems to be a moderate evaluation. At an average copper tenor of 1 percent this would make 20,000,000 tons of copper.

A difficult problem is concerned with the time of folding of the Sierra Morena in relation to the formation of the ore bodies. The pyrite and the sulphides ot copper, zinc, and lead, with sparse barite, usually represent a compact microcrystalline mass. It is locally banded, but in no place was tectonic lamination noticed.

Is the resistance to pressure of the pyrite so much greater than that of the porphyry that the pyrite may have remained without lamination while the porphyry underwent intense stress, or must we conclude that the intrusion of the ores was subsequent to the compression of the porphyries? This question can be definitely answered only by a technical research on the solidity of the compact pyrite ore compared with that of the quartz porphyry.

Has the cleavage of the porphyry been effected by lateral compression during its solidification? In some places, where sericite is found on the cleavage, the compression has obviously been later than the solidification. Such rocks resemble the highly dynamometamorphic quartz porphyry of St. Gotthard, in the Alps.

At some places the ore body obviously has penetrated from below along preexistent shear planes (fig. 100)—another proof that it is younger than the tectonic compression of the Paleozoic formations.

Cleavage and columnar folding

A peculiar fact is to be noted in regard to the cleavage. The slates are in places so much compressed in different directions that the bedding, at least along small surface outcrops, is no longer distinguishable by means of the bedding planes. The cleavage of the slate usually being vertical, it is possible that the bedding in places describes invisible anticlines and synclines. The numerous intercalations of quartzite and sandstone, however, make it possible to distinguish the bedding from the cleavage.

At a place on the road 1 or 2 kilometers north of Puebla de Guzman (pl. 35, *B*) the following directions are clearly distinguishable within the purplish arenaceous slate: Bedding plane, strike N. 70° E., dip 40°–50° SE.; strike cleavage, vertical, strike same as bedding; shearing cleavage, vertical, strike N. 20° W., thus perpendicular to the strike cleavage (coinciding on the photograph with the plane of the paper). On poor outcrops the bedding of the slate is not recognizable or is masked by cleavage.

A good example of striking cleavage is seen at the abandoned mine of Lagunazo, 5 kilometers northwest of Tharsis. The shales and slates are brightly colored in purple, brick-red, yellow, and white from decomposition by sulphuric acid, and the stratification is clearly visible, the dip being 70°–80° N. (direction of the hammer in pl. 36, *A*). The cleavage, dipping steeply south, is bent within each stratum in the shape of smooth waves, probably connected with movements along the bedding planes.

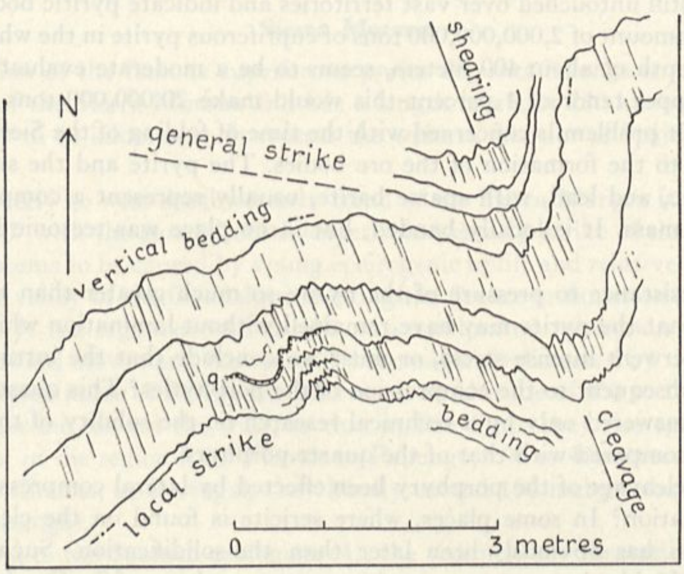


FIGURE 96.—Columnar folding of slate at Puebla de Guzman, Huelva district, Spain.

The shearing cleavage is probably caused by longitudinal compression. Unquestionably such is the case on the road at the northwest corner of Puebla de Guzman (fig. 96). There the horizontal surface of the road, if cleaned after a rain, shows folding with vertical axes, as if it were a section of a vertical plane. The bedding planes are distinctly recognizable by slight changes of the sediments and by fine quartz layers, and the shearing cleavage is traced by reddish weathering on fine joints or cracks across the greenish slate. This cleavage is vertical and strikes N. 25° W., at an angle of 50°–60° with the normal strike. I propose to call this type "columnar folding."

A similar outcrop was found 16 kilometers farther northwest, 4 or 5 kilometers southeast of the village of Paimogo. Here the axes of the folds of the slate are only partly vertical, partly dipping 60° N., according to the general position of the stratification. The nuclei of the folds are intensely crumpled.

Another place several kilometers south of Paimogo shows magnificent minor folds like the tiles of a Chinese roof, their axes pitching like the strata, 30° NW.

These examples show clearly that, instead of stretch in the direction of the major folds, the Sierra Morena has been compressed also in the longitudinal direction. Whether this "strike" compression occurred at the same time as the first lateral stress or later, after the uplift, could not be determined.

Rio Tinto

General features

The Rio Tinto mines (pls. 34, 35, *A*, 37; figs. 97, 98) are the largest mines of cupriferous pyrite in the world. Thanks to their content of copper they became the most famous copper mines of the 19th century. Recently, however, the production of copper has much decreased, while other countries have enormously increased their production, especially Katanga and Rhodesia. On the contrary, the value of pyrite as a sulphur ore, especially for the manufacture of sulphuric acid and the treatment of the phosphates for fertilizer, has increased during the last few decades, and about 1,500,000 tons was shipped annually from Huelva to European and American ports before the present depression. About 30,000 people derive their living from the Rio Tinto mines.

The decrease in the production of copper at Rio Tinto is attributed, even in recent books, to the gradual decrease of copper-bearing minerals with increasing depth. At the San Dionisio mine, however, it is clear that so simple a relation does not exist, but that the content of copper usually diminishes from the walls of the pyrite bodies toward their interior (fig. 97). Veins of almost pure chalcopyrite are found in the adjacent porphyry, even at depth. This mineral occurs in a primary form, of the same origin as the pyrite, as well as in secondary deposits, whereas chalcocite, according to Broughton Edge, is exclusively secondary.

The following analyses were made on samples taken by me from the San Dionisio mine:

	Fe	S	Cu	Zn	Pb	As	Sb	Insoluble
1..........	40.54	42.35	1.10	2.98	0.83	3.86	1.64	5.9
2..........	42.77	45.82	.47	2.22	1.35	.30	.36	6.3
3..........	43.36	46.45	1.00	2.30	1.22	1.45	1.36	2.5

Pyrite with less than 1 percent of copper is exported as a sulphur ore; pyrite with 1 to 1.6 percent of copper is generally placed on the leaching fields; and pyrite with more than 1.6 percent is treated in the high furnace, where all the sulphur is lost as fumes consisting chiefly of SO_2, and all the iron is lost as slag. Much more rational is the method of leaching and cementation. The ore is crushed to the size of gravel and is exposed in heaps for about 3 years at the surface, where the copper is leached out. The sulphate solution is led by channels toward the storage basins, from which it flows to the cementation channels, where it is precipitated on scrap iron. The residual pyrite is sold as sulphur ore.

So far as I know, the iron of the pyrite after roasting for the production of sulphuric acid is generally not used, but the natural product of oxidation—the iron caps or gossans—have been largely exploited as iron ores. It was said that in 1930, 6,000,000 tons of gossan of the Mesa de los Pinos (fig. 97) was shipped by the Rio Tinto Co. This gossan seems to be in a secondary location; the gossans in place are ordinarily useless as iron ores, on account of insufficient oxidation in their interiors.

Copper and gold have been concentrated at the base of the gossans in place, especially of that of the Corta del Norte.

The Phoenicians and the Romans seem to have confined their works to copper and gold and made hardly any use of the gossans for iron. The Romans apparently did not know the process of leaching and cementation, but, on the other hand, they were more advanced than the engineers of today in their method of melting copper. Indeed, their enormous masses of slag show hardly any trace of copper, but the modern slags are not entirely free from it.

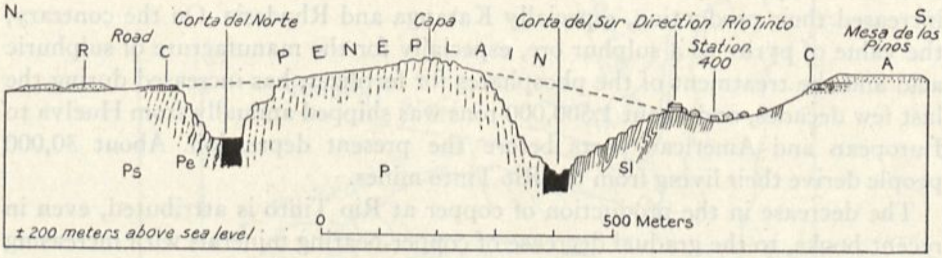


FIGURE 97.—Section through the eastern ore bodies of Rio Tinto, Spain. P, Porphyry; Pe, porphyry impregnated with pyrite (replacement); Ps, schistose porphyry; C, cap rock, impregnated with ozidized iron (red); Sl, black Carboniferous slate, bleached by H_2SO_4 at the contact of the ore; black, cupriferous pyrite; A, transported gossan, used as iron ore; R, heaps of Roman slag.

Filón San Dionisio

The filón San Dionisio is the largest known body of cupriferous pyrite in the world. The open cut resembles a terraced crater. The rim is 450 by 600 meters, and the depth is nearly 150 meters. Working down from the surface along an offshoot, the enormous body of pyrite shown in figure 98 and plate 37 was reached.

The black slate, for several meters along the contact of the sulphide ore, is bleached and transformed into a kaolinlike substance. The ore is massive and very fine grained as a rule, with a golden luster on fresh cuts but looking bluish gray at a distance, apparently stained by copper salt.

The ore lies between the porphyry and the Carboniferous slate, which is irregularly cut off by the fingerlike protuberances of the ore body. As a whole, its shape resembles that of a huge ship. The thickness reaches 280 meters at the 20th level; the depth, according to a bore, is 400 meters; and the length from west to east is about 1 kilometer, making a content of about 200,000,000 tons.

Unlike the pyrite of an ordinary lode, the mineral here is uniformly pure, without being mixed with adjacent rock material or skarn.

Filón Sur (filón de Nerva)

The name "filón Sur" designates the lode on the north side of the headquarters building (fig. 97 and pl. 35, *A*). Here also the ore is situated between the porphyry on the north side and the slate on the south side. It reaches a thickness of 30 to 75

RIO TINTO, SPAIN, FROM THE SOUTHEAST.

Vast leaching field covered with crushed pyrite from the mine, with channels leading to the basins for copper precipitation. In the middle background on a hill are the two huge chimneys of the furnaces, emanating SO_2. The mines and camps are behind the hills. Photograph by Arnold Heim, January 1, 1932.

A. RIO TINTO, CORTA DEL SUR, FROM THE WEST-SOUTHWEST.

Compare with figure 108. The wall on the left is quartz porphyry, covered with red gossan crust; the terraced slope on the right is black Carboniferous slate dipping steeply north. The cupriferous pyrite lode follows the bottom of the cut and is covered above (in center of photograph) by white clay, produced by the action of H_2SO_4 on black slate. Photograph by Arnold Heim, February 26, 1932.

B. CLEAVAGE OF THE SLATE ON THE ROAD NORTH OF PUEBLA DE GUZMAN, SPAIN.

The bedding dips 40° S. 20° E. (toward the right). The strike cleavage is vertical, with the same strike as the bedding. The shear cleavage (vertical) is in the plane of the paper, striking S. 20° E. Photograph by Arnold Heim, February 12, 1932.

meters. According to Hereza y Alvarado, the length is 1,136 meters. It is probably the eastern prolongation of the filón San Dionisio, from which it is separated by an oblique fault with transverse displacement. The combined length of San Dionisio and filón Sur is about 3 kilometers.

Within the black slate a very sharp but clearly visible synclinal fold is exposed at the surface (fig. 97).

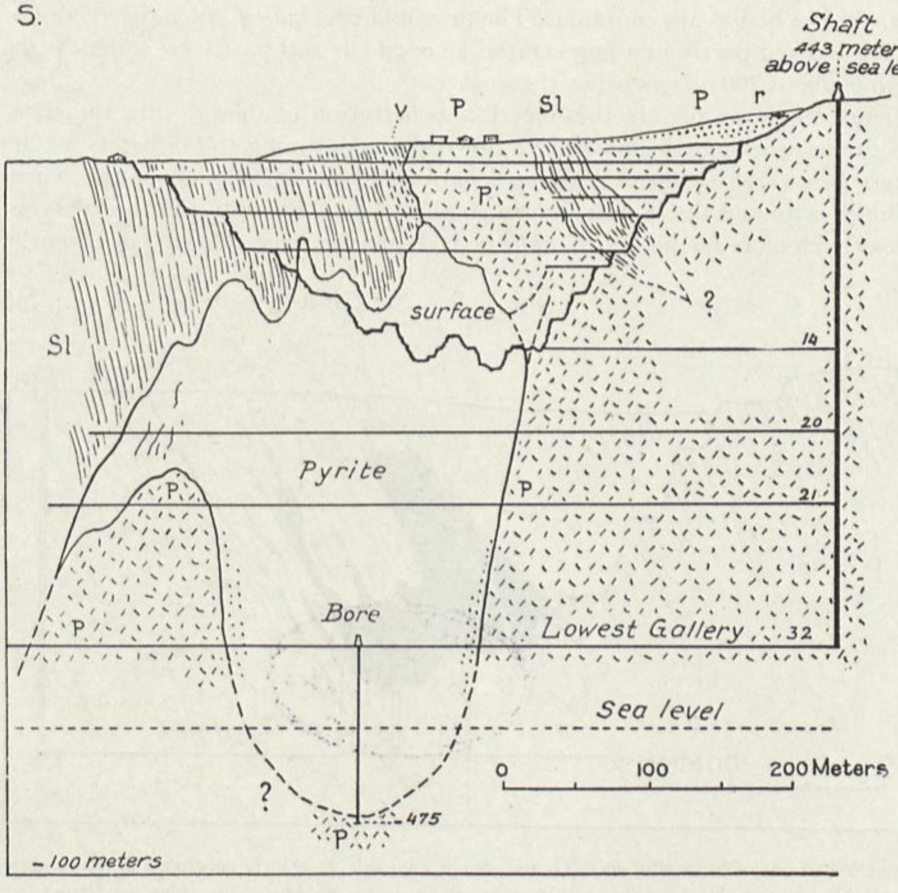


FIGURE 98.—Section of San Dionisio mine, Rio Tinto. P, Quartz porphyry; Sl, black slate, Carboniferous; v, violet to purple slate; r, red weathered surface. Only part of the galleries are indicated. (After indications by D. Williams.) The dotted margin of the pyrite body is highly cupriferous.

Filón Norte

Several smaller sulphide ore bodies are found farther north, within the porphyry. In places the porphyry is intensely impregnated by fine crystals of pyrite (fig. 97). It also contains veins of chalcopyrite, which weather to malachite and azurite and are visible for long distances as blue spots on the rock walls. Mining has been abandoned on this north side, and the cuts are partly filled with copper-bearing water.

Tharsis

In the production of pyrite the Tharsis Sulphur & Copper Co., Ltd., also a British concern, ranks second. Like Rio Tinto, Tharsis is connected with Huelva by a narrow-gage railway. The ore is of the same type as that of Rio Tinto but generally less rich in copper. Underground, the ore body is little known, and the company has made only slight geologic investigation. Unquestionably, however, the ore bodies are enormous. The principal one, called "filón Sierra Bullones," is worked partly in a huge craterlike open cut and partly by galleries to a depth of about 200 meters below the surface.

Figure 99 shows plainly the fingerlike penetration of the ore into the slate. The tunnel workings demonstrate a downward thickening to 90 meters at 200 meters below the surface. With its length of about 1,200 meters, the Sierra Bullones is among the largest known sulphide lodes. Possibly the thickness increases even more farther down, and the body may surpass that of San Dionisio.

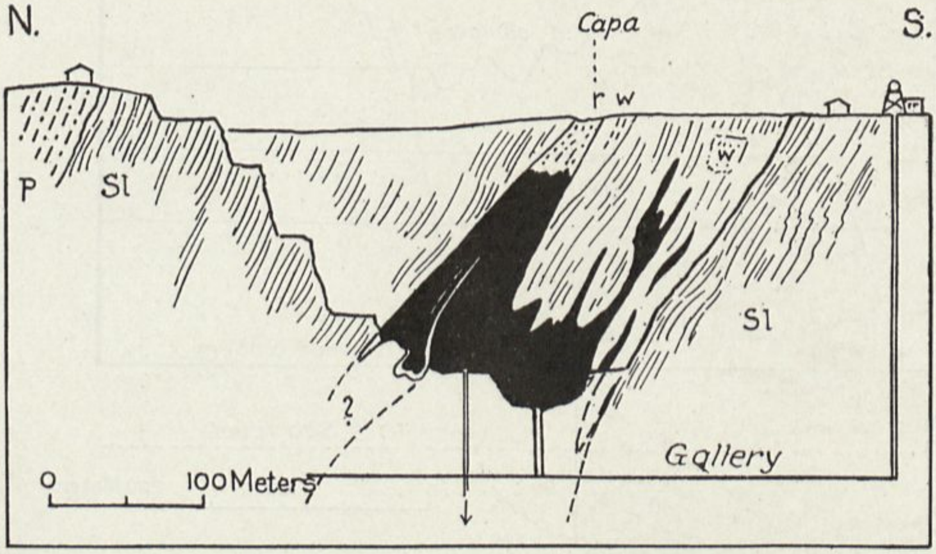


FIGURE 99.—Lode of Sierra Bullones, Tharsis, Spain, east side. P, Quartz porphyry; Sl, black slate; black, pyrite visible at surface; r, its iron cap (gossan); w, white clay (bleached slate).

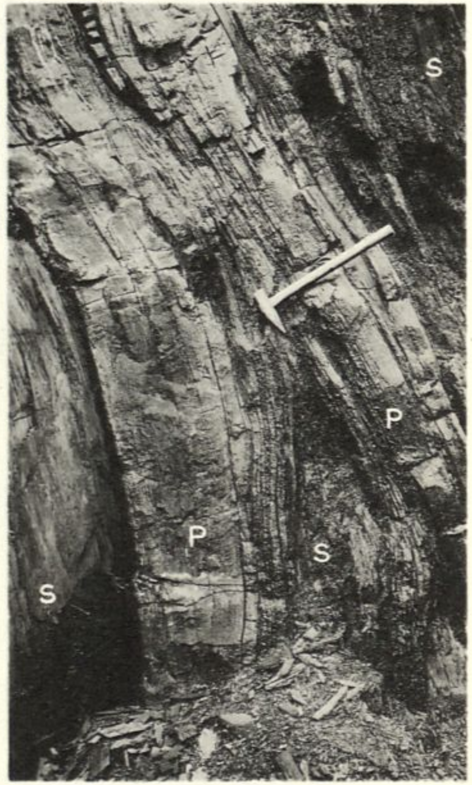
An analysis of a sample taken by me shows Fe, 43.46 percent; S, 49.08; Cu, 0.19; insoluble, 1.99; and 32 grams of silver to the ton. The ore is almost a chemically pure pyrite.

The contacts of the ore with the adjacent slates are usually sharp like those of Rio Tinto, with or without bleaching zones. This is clearly visible also at the abandoned eastern cut, where the ore body forms a compact wall on the north side of the artificial lake.

Although most of the ore bodies are compact and massive, the northern part of the Sierra Bullones shows a peculiarly contorted layer of 20 meters or less with interstratifications of black slate. One bed 1 meter thick consists of repeated layers of pyrite of 0.5–1 centimeter each within black slate. The surface

A. STRIKE CLEAVAGE OF PARTICOLORED SHALES AT LAGUNAZO, 5 KILOMETERS NORTHWEST OF THARSIS, SPAIN.

The stratification shown by the hammer dips 70° N.; the waved cleavage, of the same strike, dips south. Photograph by Arnold Heim, February 16, 1932.



B. INTERSTRATIFICATION OF SULPHIDES WITH SLATE AT HERRERIA PYRITE MINE.

P, Pyrite; S, slate. Photograph by Arnold Heim, February 12, 1932.

CORTA SAN DIONISIO, RIO TINTO, FROM THE SOUTHEAST

The boundaries of the great ore body are indicated only approximately by the dashed line, being hardly traceable at a distance when slightly weathered. Upper left, black slate; white part in center above dashed line, porphyry; dark part at upper right, inclusion of slate in the porphyry. Compare section of figure 109.

of this wedgelike part seems to be a sliding plane (fig. 99) and to continue westward, cutting the structures of the hanging slates.

Herreria

The Herreria mine, rented by the St. Gobain Co., a French company, is 4 kilometers west of Puebla de Guzman. It is connected by a special railway line of 32 kilometers with the harbor of La Laja, on the Rio Guadiana. Although of less economic importance than Rio Tinto and Tharsis, the huge open cut is tectonically one of the most interesting.

Like that of Tharsis, the ore body fingers out upward, and the shoots of the "flame" penetrate into the slate, which dips 80°–85° N. No porphyry was seen in the immediate neighborhood.

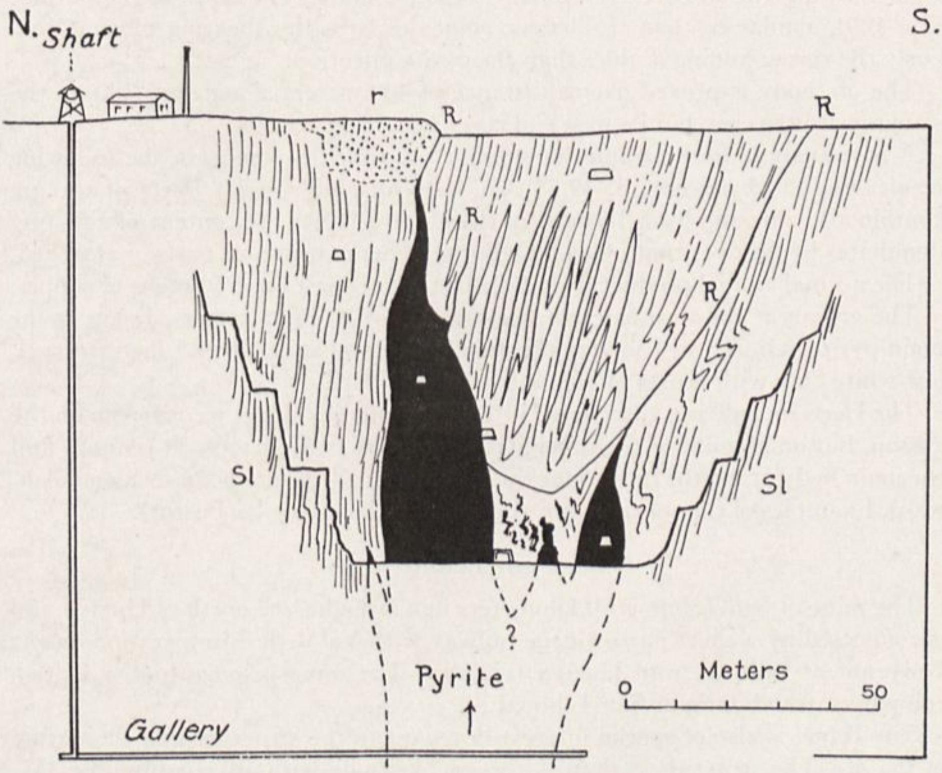


FIGURE 100.—The pyrite mine of Herreria, Spain, east side of cutting. Black, pyrite; Sl, slate; r, red iron cap (gossan); R, sliding or shear plane.

Although I was received with great kindness by the director, the underground workings could not be visited, and thus the dotted lines at depth in figure 100 are only approximate.

Two phenomena are seen better at Herreria than in the other mines:

1. "Stratified" or banded ore, of two types—(*a*) banded by minute bedding, each layer showing different size of grain of the pyrite, probably with more or

less impurities; (*b*) banded by interstratification of slate or clay. Ore of type *a* is exposed for a thickness of several meters and is banded by layers 0.5 to 20 millimeters thick, without slaty intercalations. The thick bodies at the base of the open cut are massive, without stratification. Type *b* is illustrated in detail by plate 36, *B*, which shows two stratified but rather compact layers of pyrite (P) inside of the slate (S) joining upward, as the intervening slate with pyrite intercalations pinches out. The outside boundaries of the pyrite against the slate, however, are well defined and absolutely sharp.

2. On the east side of the open cut the structure is particularly interesting. Between the two main bodies of pyrite, which follow the sliding planes or shear lines within the slate body, is a mass of intensely crushed slate, partly impregnated by pyrite. Between the two shear lines is a wedge of shale about 50 meters wide showing the most extraordinary zigzag folding. The step at the surface (fig. 100), similar to that at Tharsis, coincides with the shearing plane. Obviously the zigzag folding is older than the pyrite injection.

The ore body is proved over a distance of 400 meters along the strike of the slate toward the east, but its west end is yet undetermined.

A new analysis from samples of sulphur ore taken by me gave the following result: Fe, 42.13 percent; S, 49.28; Cu, 0.44; insoluble, 4.37. Parts of the ore contain also zinc and lead. In most of the Huelva mines the content of zinc predominates by far over that of lead. Only the richer cupriferous parts are leached.

The normal annual production is 100,000 tons of pyrite and 500 tons of copper.

The gossan at the west side reaches a depth of 20 to 25 meters. Below it the main pyrite vein is 5 to 7 meters thick and is accompanied by 0.5 meter of yellow-white clay with crusts of sulphur.

The Herreria lode was discovered in 1892. Numerous shafts were driven on the gossan, but on account of the divergence of the ore body it took 30 years to find the main body at depth. In the Huelva district not all the ore bodies widen downward. Examples of the contrary are also known (Cabeza de los Pastos).

San Telmo

The mine of San Telmo is 60 kilometers in a straight line north of Huelva and is connected by a short narrow-gage railway with Val de la Musa station on the Government railway from Huelva to Zafra. The mine belongs to the British company Arrendataria de San Telmo, Ltd.

San Telmo is also of special interest in regard to the structure and the nature of the ore. The structure is that of a wedgelike body with an axis pitching 35°–45° N. and with an oval cross section, which increases regularly with the depth. Through the kindness of Director J. B. Richardson, I was allowed to enter the shafts and galleries. At the depth of the ninth gallery, 180 meters below the surface, the ore body is 160 to 180 meters wide and 100 meters thick. Its sharp boundaries are in contact with the slate on the upper side and partly with the porphyry on the lower side (fig. 101). The shape of this main ore body is very similar to that of the great body of hematite ore of the Minas del Rif, near Melilla, Morocco.

The ore body is massive and contains an unusual variety and mixture of metallic sulphides and sulphates. In the interior of the pyrite mass, which is locally very rich in primary chalcopyrite, are irregular bodies of zinc and lead sulphides with some silver and gold. They are of the same microcrystalline structure as the pyrite and in many places are banded, showing different layers within the pyrite. Some of the ore contains as much as 30 percent of zinc and 10 percent of lead. Many of these dense grayish mixed ores also contain as much as 26 percent of barite. The intimate mixture of these minerals makes their separation very difficult. A special plant has been built for grinding, sifting, washing, and flotation. The problem of economic separation is not definitely solved. Two new analyses of such mixed ores from San Telmo collected by me have given the following result:

	Fe	S	Cu	Zn	Pb	Insoluble (SiO_2, $BaSO_4$)	Ag (grams per ton)
1.	12.65	29.04	2.08	26.34	0.60	24.57	220
2.	31.02	41.09	1.45	13.35	.34	12.35	36

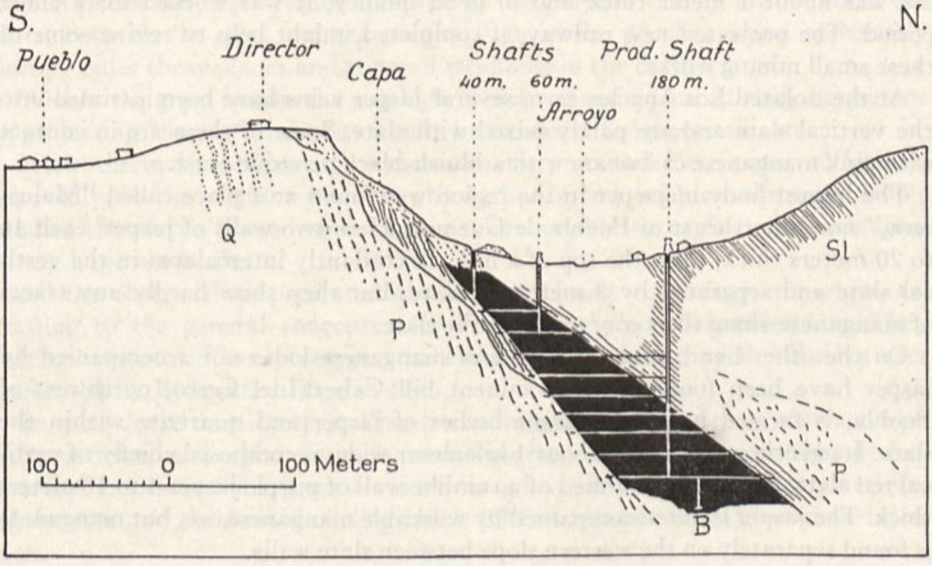


FIGURE 101.—Section of the San Telmo mine, Spain. Q, Quartz; P, porphyry; Sl, slate; B, ore.

Manganese ores

There are innumerable small manganese deposits in the Huelva district. Their origin is totally different from that of the large stratified manganese deposits of the province of Badajoz, farther north. In dozens of places these ores of manganese carbonates and silicates with a more or less deep oxidized cap were worked locally during the World War but are lying idle at present.

Broughton Edge has drawn attention to the peculiar relations of the manganese lodes to the cupriferous pyrite lodes of the region. Although accompanying each other, they are nowhere mixed in one ore body.

Commonly, but not everywhere, the manganese ores are associated with purple jasper. The jasper, being more resistant to weathering, forms rock walls or crests in many places on the hills and thus is easily recognized at a distance; but it is not invariably accompanied by manganese ore.

A few examples will suffice to characterize the tectonic position of the manganese deposits.

At Alcornocal a lode 0.5 to 1.5 meters thick was worked with a shaft to a depth of 48 meters. It dips conformably with the adjacent jasper and with the embedding slates at an average angle of about 65° NE. The ore is a whitish-brown carbonate, which is oxidized at the surface to black MnO_2. By roasting it in a furnace, the primary ore was concentrated before exportation.

The lodes 7 to 8 kilometers north of Puebla de Guzman are directly associated with vertical jasper veins. They are also close to schistose quartz porphyry, although not in contact with it. Numerous open cuts and small shafts were dug along the jasper outcrops, some of them touching manganese veins. Where this ore was about 1 meter thick and of good quality, it was worked for a short period. The projected new railway, if completed, might help to revive some of these small mining works.

At the isolated Los Angeles farm several jasper veins have been intruded into the vertical slate and are partly mixed with slate. Some of them are in contact with pink manganese carbonate with a bluish-black peroxide crust.

The largest body of jasper in the region was found at a place called "Malustera," north-northeast of Puebla de Guzman. Here two walls of jasper, each 16 to 20 meters thick, form the top of a hill, concordantly intercalated in the vertical slate and separated by 3 meters of slate; but they show hardly any traces of manganese along their contacts with the slate.

On the other hand, some examples of manganese lodes not accompanied by jasper have been found. The prominent hill Cabeza del Cerco, northwest of Puebla, is formed by the resistant bodies of jasper and quartzite within the slate. Its gentle north slope, about 1 kilometer wide, is composed chiefly of vertical red slate. The crest is formed of a ruinlike wall of purple jasper 4 to 10 meters thick. The jasper is not accompanied by workable manganese ore, but manganese is found separately on the western slope between slate walls.

The only large manganese deposit visited by me in the northwestern part of the Huelva district is at El Mensagero. There the jasper, with a normal westerly strike and vertical walls, is intercalated within the schistose porphyry, and the manganese ore is found within the jasper. The ore is oxidized to MnO_2 and forms a black wall. It is in part so much mixed with jasper that the good ore has to be sorted out by hand. Not only does the ore contain jasper, but the jasper, especially where it is schistose, contains streaks of manganese ore.

Conclusions

The cupriferous pyrite bodies of Huelva, so far as studied and figured above, are of the shape of igneous intrusions. They are all longer and deeper than wide, forming elongated lenses or shiplike bodies. With slight exceptions, they conform to the attitude of the steeply tilted Paleozoic strata and folds as well as to the strike cleavage and to the elongate shape and schistosity of the intrusive quartz porphyry. They were thus intruded into the tilted formations after the first strong tectogenetic compression of Carboniferous time.

The open cuts at Tharsis (fig. 99) and Herreria (fig. 100) show that the pyrite followed older shear planes, locally cutting the crumpled strata at their contact. The injection of the ore bodies was later than the main tectogenetic movement of Carboniferous time.

The strong compression caused by the Hercynian stress resulted not only in normal folds, but also in intense cleavage. Two types could be clearly distinguished, which I have called "strike cleavage" and "shear cleavage." Furthermore, folds and crumples are found not only in normal position, but locally also with vertical axes, caused by longitudinal compression. These types I have called "columnar folds."

Although the larger slate areas (southern Portugal) are barren, the distribution of the ore bodies coincides with the region of quartz porphyry intrusions. But in detail the ores are not confined to the porphyry: they are found in the slate, between the slate and the porphyry, or in the porphyry, and apparently occupy older shear planes and zones of weakness in the earth's crust.

Within the great bodies the sulphide ores are massive, but at their borders or in projecting "fingers" they may locally be banded, like igneous silicates.

Hydrothermal replacement or metasomatic processes have occurred locally, especially at the contact with porphyry, but in my opinion the microscopic studies that have proved such processes are unable to explain the formation of the huge ore bodies.

All the observations presented above point clearly to a magmatic origin, according to the general conception of Vogt, Niggli, and Schneiderhöhn. They further confirm in every respect the excellent description of the Huelva ores presented by Broughton Edge in 1926.

In their dense or microcrystalline structure the sulphides are in contrast with the pyritic veins of other countries, with their large crystals influenced by hydrothermal processes. This structure is explained by the high thermal conductivity of the ores and their rapid cooling below 800° C., immediately after their injection.

The banded ores may be explained by gradual cooling along the contact with the adjacent rock, influenced by exhalation, partly also by flowage in a semiliquid condition, or by injection similar to the well-known flowage and "stratification" of some igneous silicate rocks (fluidal granite and porphyry). Tectonic lamination after consolidation of the ore has not yet been observed.

The manganese ores of the Huelva region with the accompanying jaspers are considered hydrothermal products, younger than the sulphide ores but possibly derived from the same magmatic source. This conclusion is confirmed by the observations of Broughton Edge, who has found a jasper vein traversing a pyrite body.

If the interpretations above set forth are correct, the succession of events was about as follows:

1. Deposition of Cambrian to lower Carboniferous marine sediments.
2. First intense Hercynian compression with normal and columnar folding and with strike and shear cleavage. General strike northwest (north of Sevilla) to west (Portugal). Upper Carboniferous.
3. Intrusion of numerous elongated bodies of quartz porphyry during further compression.
4. Intense compression after consolidation of the porphyries.
5. Magmatic injection of highly mobile sulphides, especially of copper-bearing pyrite along weak zones and shear planes. Rapid consolidation under pressure several kilometers below the surface.
6. Hydrothermal injection of jasper with manganese ores at end of Paleozoic era.
7. Denudation and peneplanation since Hercynian movement.
8. Slight further displacements of peneplain in post-Paleozoic time.
9. Unequal Quaternary uplift of the Sierra Morena with renewed erosion.

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Postscript

A year after the foregoing paper was delivered the following publication was issued: Williams, David, The geology of the Rio Tinto mines, Spain, with discussion: Inst. Mining and Metallurgy Trans., 1933–34. This fundamental paper, which could have been worked out only by an experienced geologist of the Rio Tinto Co., contains the first detailed geologic map of the mines, scale 1:10,000. Although some points in my paper could be improved, my conclusions are not altered. See also discussion by me after Williams' paper (idem, pp. 654–656), containing figure 139, "Sketch of the Mina Herrerias opencast, western side," which is a supplement to this Congress paper.

Copper-ore regions of the Union of Soviet Socialist Republics

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General geologic characteristics

The chief copper-ore deposits of the Soviet Union are found in the Ural Mountains, in Kazakstan (Kazak Steppe and Altai mining districts), in Central Asia, and in the Caucasus. Other regions which contain deposits of lesser importance include the Kola Peninsula and Karelia, Novaya Zemlya, the Minusinsky district, the Yenisei-Norilsky district, the Lena district, the northwest Baltic region, and the Far East.

Ural Mountains

The Ural Mountains are made up largely of folded sedimentary rocks of Paleozoic age, each system of which is represented. Gneisses and slates questionably assigned to the pre-Cambrian are found in the central part of the range, and in places the Paleozoic sediments are notably affected by dynamic metamorphism. Igneous rocks of several ages are widespread throughout the mountainous region. Most of the igneous rocks belong to the Variscan (Carboniferous) cycle and include both effusive rocks (melaphyre, albitophyre, etc.) and intrusives which range in composition from granite through granodiorite and gabbro to dunite. Some lavas and small intrusive bodies of granodiorite characterize the Caledonian cycle; and in the vicinity of the river Usa, in the northern Ural Mountains, basalt flows of Jurassic age are known.

The earliest folding in the Ural Mountains is of Caledonian age, but the greater part of the deformation was accomplished during a cycle that began in the Middle Carboniferous and was completed by the end of the Permian. These ancient folded mountains were eroded by the end of the Mesozoic era but were again uplifted by block faulting during Quaternary time.

The Pre-Ural on the west and southwest side of the range is underlain by upper Paleozoic sedimentary rocks. The Permian portion of the section includes copper-bearing sandstones. The Trans-Ural east of the mountains is a steppe region made up of Mesozoic and Tertiary sediments, which overlie the eroded Paleozoic beds.

The known copper deposits are related to the Carboniferous intrusions and are located mainly in the central and southern Ural Mountains and in the Trans-

Ural; the northern part of the range has not yet been adequately explored. Contact-metamorphic deposits are common but are of low grade. Vein deposits of copper (Pyshminsko-Kliuchevskoie, Blagodatny, and others) and deposits of the "porphyry copper" type are not numerous in the southern Ural Mountains. Disseminated copper ores in gabbro (Volkovski deposits and others) are widely distributed but are small.

Copper-bearing pyritic lodes yield by far the greater part of the copper production from the Ural Mountains. These lodes are localized in zones of quartz-chlorite and quartz-sericite schist which are 2 to 5 kilometers wide and 300 to 400 kilometers long and which are believed to represent zones of reverse faulting. Small intrusions of albitophyre, etc., are also restricted to these zones and are genetically related to the copper deposits.

Kazak Steppe and Altai

The Kazak Steppe and Altai mining districts form the northeastern and eastern parts of Kazakstan and are regions of low plateaus and isolated mountain massifs. Sedimentary rocks containing representatives of all the Paleozoic systems are widely developed in both districts; they are dominantly marine, but are in part continental. Locally there are small areas of pre-Cambrian gneiss and slate. Marine Mesozoic and Cenozoic formations are absent, except for Paleocene beds on the northwest and west boundaries of the Paleozoic rocks, but basins of coal-bearing Jurassic and Tertiary sediments are present in places. The igneous rocks are chiefly of Variscan age; they include both effusive porphyry and granite and granite porphyry. Intrusive and extrusive rocks of both pre-Cambrian and Caledonian age are much less widely distributed. The Paleozoic rocks were strongly folded in both the Caledonian and the Variscan epochs. Associated with the folds are large overthrusts that have a northwesterly or northerly strike.

The ore deposits of the region are almost exclusively of Variscan age and are localized along the overthrust fault zones. Granitic rocks are commonly found in these zones in the vicinity of the ore deposits and have metamorphosed the invaded rocks.

Several types of copper deposits occur in the region. Mineralized breccia zones that enclose quartz or quartz-barite veins are widespread, especially in the Kazak Steppe. Closely related to these deposits are deposits of the "porphyry copper" type, which are localized by faults and are marked by masses of introduced quartz and small bodies of granitic rocks (granite, monzonite porphyry, and felsite). More than 200 of these deposits are known; in some of them the quartz masses cover an area of 2 to 5 square kilometers or more.

The copper-impregnated sandstones of Djeskasgan are distributed throughout an area of 1,000 square kilometers but are distinct from the sedimentary copper deposits, which are of only local occurrence.

Copper-bearing veins are abundant but are commonly rather shallow (the maximum depth is generally 20 to 300 meters) and of small size. The Uspenski mine and a few others are exceptional. Contact deposits are not known in the region.

Central Asia

In 1931 large ore bodies of the "porphyry copper" type were discovered in the Almalyk region. So far five potentially productive areas have been found in Tien Shan. This region is made up of high mountainous country, built up chiefly by Paleozoic sedimentary rocks, with some pre-Cambrian gneisses in the north and with the intermontane belts underlain by Mesozoic and Tertiary sediments. Block faulting during Quaternary time is believed to have produced these topographic characteristics. Both the stratigraphic succession and the geologic structure resemble those found in Kazakstan and to a lesser extent those in the Ural Mountains. The igneous rocks are mainly of Variscan age and include effusive porphyry and granitic and granodioritic intrusives.

In the more northerly folded belts, in which the "porphyry copper" deposits are found, the dominant orogenic period was the Variscan, but Caledonian and older structures are also found. To the south the Variscan folds are cut by block faults of Alpine age. Here sedimentary deposits of copper occur in the younger Mesozoic sandstones.

Caucasus and Transcaucasia

Caucasus and Transcaucasia are both included in the inner zone of the Mediterranean geosyncline, which is continued on the extreme southeast of the Soviet Union by the southern arches of Central Asia (Cavkazide).

In the Caucasus region the Great Caucasian Ridge contains cupriferous veins and pyritic deposits (Devdorak, Buron, Belokany, and others). The copper deposits are believed to be localized by shear zones in Mesozoic and older formations.

Transcaucasia is characterized by the volcanic character of the Cenozoic, Mesozoic, and Paleozoic. Variscan or older folds are not found. Numerous intrusions of Alpine and Kimeridgian ages are characteristic; with these are associated the ore deposits of the region, particularly the copper veins (Zangezur and others), pyrite lenses (Allaverdy, Shamlug, and others), contact deposits (Miskhana and others), and "porphyry copper" deposits (Agarak and others).

Kola Peninsula and Karelia

In the Kola Peninsula and Karelia region, which adjoins the Central Russian Platform on the extreme northwest, there are several as yet slightly investigated copper deposits. Pre-Cambrian rocks underlie most of the country. Some lower Paleozoic sediments are found in the southern part of Karelia and on the periphery of the peninsula. The latest intense orogeny is of Guronian age; but it is believed that a northeastern belt of deformation, which goes through Karelia, is Caledonian; and Hercynian disturbances may be present on the northern border line of the Kola Peninsula.

Caledonian intrusions of norite, peridotite, etc., are thought to have played the chief part in the copper mineralization on the Kola Peninsula. The contacts of these intrusives with mylonitized gabbro and with gneiss are in many places impregnated with disseminated copper and nickel sulphides. Copper-bearing veins of magnetite and schlieren in the norites, which contain pyrrhotite, chalcopyrite, and pentlandite, are also common. Cupriferous quartz veins are less abundant. The main ore zones commonly strike northeast, parallel to structural features, and are kilometers in length.

There are two types of copper deposits in Karelia—(*a*) copper sulphide impregnations in altered diabase and gabbro-norite, bordering quartz-carbonate veins; (*b*) copper ore at the contact between diabase and Cambrian quartzite (Voronobordkoie, Boitzkoe, and others). Molybdenite is present in these ores at many places.

Novaya Zemlya

The island of Novaya Zemlya, which is a mountainous region, closely resembles the Ural in its geologic structure. The same marine Paleozoic formations are present, and so are the same types of folds, of Caledonian and Variscan age. The igneous rocks are chiefly Variscan diabase and granite. Mesozoic basalts are reported to occur.

The copper ores are found within an area of 20 square kilometers. Disseminated native copper and copper sulphides occur in lodes from 20 to 100 meters in width and many thousands of meters in length. The lodes, composed largely of pyritized breccia, lie between wall rocks of folded and epidotized diabase. Carbonate veins containing chalcopyrite occur in the limestones of the central part of the island. Molybdenum is associated with the copper in the vicinity of acidic intrusive rocks, and locally scheelite and cassiterite have been found.

Minusinsky district

The Minusinsky copper-ore district is part of the Ural-Yenisei folded zone. Pre-Cambrian and marine lower Paleozoic rocks are for the most part absent, however, the most widely distributed sediments being continental middle and upper Paleozoic formations. The folding belongs dominantly to the older epochs of diastrophism, Alpine disturbances being limited to block faulting, mainly in the southern part of the region. The igneous rocks are chiefly pre-Variscan, but some Quaternary basalts are known along faults.

Most of the copper deposits in the region are of the contact-metamorphic type (Ulia, Kayalyh-usen, Temirskoie, and others). The ore is composed of disseminated sulphides in skarns or in the endomorphosed intrusion. Pyrite deposits of the Ural type are not abundant (Mainskoie) and are considerably faulted. Magnetite is present in large quantities in such deposits, and there is little enrichment. Quartz and carbonate veins containing copper are small; more interesting are the veins in the limestones along folded belts (Basyrske and others). There are numerous epigenetic deposits formed by impregnation of conglomeratic sandstones and effusive rocks of Devonian age, but these have not been thoroughly investigated. The mineralized region probably widens toward the south (in the Uriankhaiski region and eastward), where, within the boundaries of the eastern Saian Mountains, there is a series of copper deposits in the lower Paleozoic sedimentary rocks and in melaphyres. Locally granite dikes containing disseminated copper sulphides are found.

Norilsky district

The Norilsky district is east of the lowlands of the Yenisei River and borders the northwestern section of the Siberian massif. The Hercynian fold zone, which adjoins the massif, extends northwestward in the direction of Taimur. The oldest formation exposed in the district is a thick Silurian limestone. The upper Paleozoic is represented by the so-called "Tungus Svitai," the usual thickness of which is 1,000 meters or more. Individual members of this formation in many places lens out along the strike. The folding in the region commonly strikes northeast, and tends to be more open westward.

A group of gabbros or diabasic intrusions are believed to have induced the copper mineralization in the Norilsky region. They occur as stocks, sills, and dikes intruded in the middle of the lower or productive section of the "Tungus Svitai." South of Norilsk the effusive equivalents of the intrusions contain copper deposits. In the Yenisei mountain range, however, the copper and polymetal deposits are thought to be related to granitic intrusions that are possibly of Variscan age.

Pre-Lena district

The Pre-Lena district has long been known to contain sedimentary copper deposits. These are found in tilted and faulted red sandstones of Lower Silurian age and are overlain by horizontal light-gray limestones and sandstones. The deposits have a wide areal distribution: they have been traced for 500 kilometers along the Lena River downstream as far as Kirensk and for 20 kilometers on each side of the river. Two ore zones have been located. The region is rather mountainous, being within the boundaries of the Caledonian folded zone that lies on the southeastern outskirts of the Siberian massif. The region is underlain by intensely crushed pre-Cambrian rocks and less sharply deformed Paleozoic sediments (limestones, red beds, sandstones, etc.) cut by Caledonian intrusions. Large faults were developed during Paleozoic time, and these have localized wide trap dikes.

Eastern Transbaikalia and Baikal-Vitimsk highlands

The copper deposits of eastern Transbaikalia and the Baikal-Vitimsk highlands are situated in a region of Alpine orogeny. The ore occurs in lodes or veins, which commonly strike northeast and are believed to be genetically related to granodiorites or granite porphyries that are also of Alpine age. Small quantities of antimony, arsenic, lead, and gold are generally present in the deposits and reflect their relationships to the Tertiary intrusives. A few of the deposits are of the contact-metamorphic type and occur in skarns; most of them, however, are mesothermal veins. The veins commonly have a strike length of 250 meters, and some extend for 600 meters. The wall rocks are limestone and slate, or, in a few places, the intrusive rock. Quartz is the most abundant gangue mineral. The grade of these deposits ranges from 1 to 3 percent or even 7 percent of copper, and some of them contain from 10,000 to 20,000 tons of metallic copper.

Far East

In the parts of the Far East where Alpine orogeny and volcanic activity are known, copper-bearing veins have been found. These veins, however, have been only slightly prospected.

Genetic types of copper deposits

The genetic types of copper deposits that are of economic interest in the Soviet Union are as follows:

1. Copper deposits formed by concentration in molten magmas (in association with nickel and platinum).
2. Contact-metamorphic deposits of copper.
3. Hydrothermal deposits:
   (*a*) Pyritic-copper deposits.
   (*b*) Vein deposits of copper.
   (*c*) Impregnations in sandstone (Djeskasgan type).
   (*d*) Deposits of the "porphyry copper" type.
4. Sedimentary deposits of copper in sandstones.

Native copper deposits, with associated zeolites, are found in Novaya Zemlya, the Ural Mountains, Kazak Steppe, Ketmensky Ridge, the Minusinsky region, the Djidinsky region, the Commander Islands, and particularly in the Upper Lake region. In these regions the deposits, which are of hydrothermal origin, are restricted to amygdaloidal extrusive rocks (mainly melaphyre and to a lesser extent diabase, porphyry, and basalt), the amygdules of which are filled with native copper, cuprite, prehnite, zeolites, calcite, quartz, and other minerals. Carbonate and other veins are also commonly present, and epidotization of the wall rocks is almost universal. The deposits have not been prospected in depth.

Nickel-copper ores

Nickel-copper ores of magmatic origin are not widely distributed in the territory of the Soviet Union. They are so far known only in two regions—the Norilsky region of western Siberia and the Kola Peninsula. The number of known individual deposits in each region is large and is increasing as a result of prospecting. The deposits have an appreciable content of the platinoid metals, a factor which will affect the treatment of the ores. On the Kola Peninsula (Monche, Wolf tundra) schlieren within masses of norite contain erratically disseminated sulphides (pyrrhotite, chalcopyrite, and pentlandite). Small mineralized intrusions of the norite, together with similar masses of peridotite and pyroxenite, commonly occur near the contacts of large gabbro massifs with Archean gneisses. These contacts have a northerly strike and dip steeply to the east. The area of the ores (schlieren) reaches 100,000 to 150,000 square meters. Drilling has proved the presence of sulphides to a depth of 50 meters, from which the reserves have been calculated. Along the contacts of the gneiss masses there are belts as much as 1 kilometer long and 20 meters wide, in which sulphides are found either as disseminated grains or in thin veinlets; and within the peridotite there are veins of titaniferous magnetite which also contain sulphides. These have a copper content of as much as 4 percent and a nickel content of 0.5 percent or less.

In the Norilsky region there are, in addition to the disseminated ores, copper-nickel ore bodies (containing platinoids) of higher grade. These are commonly found along the basal portions of thin trap sills, a large number of which make up the greater part of a 400-meter thickness. In these ores the average content of nickel and copper (1 to 3 percent) is considerably higher than in the disseminated ores, but the reserves are much smaller.

Contact-metamorphic deposits

Contact-metamorphic deposits of copper are widely distributed in almost all the copper-ore regions of the Soviet Union, especially in the Ural, Central Asia, Kazak Steppe, and Minusinsky regions. The exploitation of the contact deposits in the Ural Mountains was started in the 18th century, and in the 19th century these deposits, together with the copper-bearing Permian sandstones and copper-quartz veins, were the basis of the copper industry of the country. On the whole they yielded less than 270,000 tons of copper. In the Caucasus the Kedabedsky mine was worked for more than 50 years (1867–1914) and produced about 60,000 tons of copper from ores with a copper content of 3 to 4 percent. In the Minusinsky region, from 1908 until 1915, the ores mined contained from 1.2 to 4.5 percent of copper. Contact deposits were exploited in the Altai in the 19th century. This type of copper deposit contains 3 to 4 percent of the known ore reserves of the Soviet Union.

Among the contact deposits it is possible to distinguish three groups:

1. Copper-magnetite deposits with a content of copper up to 1 percent or more are widely distributed in the Ural, Kazak Steppe, and Central Asia. Reserves of copper in such ores in the Ural region are estimated to be 270,000 tons, and in Central Asia and Kazakstan 50,000 tons.

2. Copper deposits in skarns are widespread (Mednorudiansk, Turinskiy, Gumeshevska, and others in the Ural and Minusinsky regions and elsewhere).

3. In the Kedabedsky deposits of the Caucasus, side by side with skarn deposits, are found similar ores in quartzite. These occurrences not only point to the contact-metasomatic genesis of this entire group of deposits but also indicate hydrothermal processes in the formation of the ores.

In the Ural Mountains, Kazakstan, and Central Asia the contact type of deposit is related to the Hercynian intrusions of granodiorite, which have invaded sedimentary and effusive rocks of middle Paleozoic age. Most of the intrusive rocks have the composition of granite, monzonite, or granodiorite, but dioritic border facies are common. In most of the deposits there are, in addition to the major intrusions, dikes of diabase and diorite porphyry, which have been introduced along a system of ancient tectonic cracks. These fractures are readily distinguished from a group of younger faults that cut the ore bodies. Augite and garnet are the dominant constituents of the skarns; among the sulphides, pyrite and chalcopyrite are the most abundant, and pyrrhotite, galena, sphalerite, and molybdenite are less common. There are relatively few contact deposits in eastern Siberia (Aginski, Namamski, and others). These are related to small acidic intrusives (aplites, porphyries, and granites) of Alpine age. The intruded rocks are lower Paleozoic. The ores contain, in addition to copper, arsenic, antimony, and the precious metals.

Hydrothermal deposits

Hydrothermal deposits are the most widespread type of copper deposit in the Soviet Union.

Lodes of copper pyrites.—The lodes of copper pyrites are similar to the deposits of Rio Tinto and of Shasta County, California. They are most common in the Ural region and are less abundant in the Caucasus, Kazakstan, and Siberia. Some of the deposits in the Ural region (Ejovka and others) were mined for copper or pyrite in the 19th century. In the Caucasus efficient development of the Allaverdy deposit was started in 1889, and the mine has produced since that time 1,000,000 tons of ore and about 40,000 tons of copper. In the other regions (Maikain, Belousovskoie, Mainskoie, etc.) there has been scarcely any output of ore, as the deposits are either being prospected or are being prepared for exploitation.

In the Ural Mountains, mainly on the eastern slope in the central and southern parts of the range, there are known today as many as 100 individual pyrite deposits, which have been grouped into six mining-plant combines (Krasnouralski, Kalatinski, Degtiarinski, Karabashski, Tanalyk-Baimakski). Almost all the deposits are concentrated along a longitudinal belt of highly sheared and hydrothermally altered rocks, which were originally in part of sedimentary origin and in larger part of volcanic origin but are now metamorphosed into quartz-chlorite and quartz-sericite slates. The dip of the lodes is commonly 70°–80° E., but some of the ore bodies have the form of anticlinal and synclinal folds of diverse strike and plunge (Degtiarka). A low angle of plunge is characteristic of several such lodes in the southern Ural region (Sibai, Tuba, etc.), and commonly a series of lodes occur, each concordant in strike and plunge with the overlying and underlying lodes (Kalata, Karpushicha, etc.).

The ore shoots range in length from 50 to 600 meters and exceptionally even to 4,000 meters (Bliava, Degtiarka); the thickness is 50 meters and more (Bliava). Many of the deposits have been developed to depths of 300 to 400 meters. A group of large deposits (Karabash, Degtiarka, etc.) have been proved to depths of 400 to 600 meters and are believed to extend downward as much as 1,000 meters. Horizontal sections of the ore bodies range in area from 1,000 to 13,000 square meters (Karabash, Tissovskoe), 40,000 square meters (Degtiarka), and 75,000 square meters (Bliava). The ore reserves in individual large lodes may reach many millions or even tens of millions of tons (Krasnogvardeiskoe, Degtiarka, Karabash, Bliava, etc.). Massive pyrite is by far the most abundant constituent of the lodes, but in many places there are disseminated sulphides in the wall rocks. These are commonly on the hanging-wall side and may have dimensions of many meters. The copper content of such disseminated ores ranges from 0.7 to 2 percent (Levihi, Karpusjika, Degtiarka, Karabash).

Typical ore from the pyritic lodes contains 90 percent of sulphides, comprising chalcopyrite, tennantite, sphalerite, and locally galena, in addition to pyrite. Magnetite and pyrrhotite are rare. The most common gangue minerals are quartz, sericite, chlorite, and barite. In many of the deposits gold is concentrated in the oxidized or leached zones.

The copper content in these pyritic ores is variable, not only between individual deposits but between different parts of the same deposit. Ore shoots are commonly found along the hanging-wall side of the lodes. The average copper content in the developed ore shoots ranges from 1.4 to 2.7 percent. The zinc content is commonly from 1 to 2.7 percent, but in some deposits (San Donato, Karpushikha, Kuznechikha) the zinc content rises to 5, 8, and 14 percent. The gold content is commonly from 1 to 3 grams to the ton, but in the southern Ural region it increases to 6, 9, and 30 grams to the ton. The silver content is about 10 times as large as the gold content. An enriched zone is found in most of the deposits, extending to depths of 100 to 200 meters.

The ore reserves in the pyritic lodes of the Ural Mountains, including the newly discovered deposits in the southern Ural region, exceed 170,000,000 tons; it is believed that eventually the quantity will be in excess of 200,000,000 tons. Pyritic deposits (Arshinski) are also present on the western slope of the Ural Range, between the dolomites and phyllites of the central Ural zone, and there are indications that similar lodes are also present in the northern part of the range.

The pyritic deposits of Makain, in Kazakstan, are also of Variscan age and are related to intrusions of quartz albitophyres. There are ten separate lenses and veins in a zone of strongly sheared porphyry and quartz-sericite slate that has a northeasterly strike. Quartz and barite veins are also found. The lenses have a maximum length of 500 meters and an average thickness of 25 to 30 meters. Prospecting to a depth of 200 meters showed the copper content of the pyritic ore to be 1 percent, increasing, in the enriched zone, to 1.3 percent, 3.6 percent, or more. There is a high content of gold in the capping. The reserves exceed 100,000 tons.

The Mainski deposit, in Siberia, differs in its considerable content of magnetite and in the comparatively small amount of alteration suffered by the effusive rocks that form the wall rocks of the ores.

The pyritic lodes of the Caucasus belong to the Alpine epoch of mineralization. The ore bodies occur along fault zones in effusive or sedimentary rocks, which extend for 2 kilometers along the strike and have been followed for 400 or 500 meters down the dip (Allaverdy, Shemlug, etc.). The thickness of the ore shoots is 10 to 12 meters or less. The average copper content in the Allaverdy ores ranges from 2.5 to 7 percent; the gold content is as much as 1 gram to the ton, and the silver content as much as 80 grams to the ton. The Shemlug deposits contain 3.8 and 3.4 percent of copper. The Belokana deposits differ from the others in their high content of pyrrhotite.

Vein deposits.—The vein deposits contain only about 2 percent of the determined reserves of copper in the Soviet Union. Some mines in the Ural have reached a depth of 250 meters, and the famous Uspenski mine, in the Kazak Steppe, has worked a rich vein of bornite to a depth of 200 meters. This mine has produced, since the discovery of the vein in 1877, about 215,000 tons of copper; but the remaining reserves do not exceed 30,000 tons, having a copper content in two types of ore of 5.9 percent and 1 to 2 percent.

A group of rich copper-bearing veins in Altai was worked in the 18th and 19th centuries. At the end of the 19th century the output of copper ores ceased, owing to the exhaustion of the rich (5 to 11 percent) oxidized ores, which had changed in depth to pyrite ores rich in zinc. Most of these deposits are within an ancient massif of surface volcanic rocks (porphyry, diabase, and tuff), which are locally highly sheared, or within phyllites and limestones. In a few places the veins cut tuffs and quartz porphyry of Devonian age. The veins are characteristically branched. They range in length from 50 to 310 meters and in thickness from 0.6 to 6 meters. The average width is 1 to 2 meters. Mining has reached a depth of 133 meters, but the lean pyritic ores extend still deeper. Quartz is the most abundant gangue mineral. The oxidized zone is 40 to 60 meters in depth, and an enriched zone of covellite and sooty chalcocite is well defined.

Copper-quartz veins of the Kazak Steppe and Central Asia are genetically and morphologically identical with those of Altai, but the hypogene ore is of lower grade, and the zone of enrichment is less well developed. They are found both in igneous rocks (intrusive and extrusive) and in sedimentary rocks (limestones and sandstones). The veins are followed by porphyry dikes in many places. The vein filling commonly consists of quartz and disseminated sulphides and has a width of 1 to 4 meters. The average copper content is not more than 2 or 3 percent. Zinc and lead are present in almost all the veins. The veins in Central Asia commonly have low dips (10°–25°) and are 2 kilometers in maximum length, with a thickness of 0.3 to 2 meters. The veins cut granodiorite and are localized by faults or by porphyry intrusions (Uchkatly-Miskai). The copper content is 2.24 percent; lead, 2.25 percent; and zinc, 1.2 percent.

The gold- and copper-bearing quartz veins of the Ural region (Blagodatny, Beresovski, etc.) are facies of gold-quartz veins, containing almost invariably copper, zinc, and lead. The veins are genetically connected with a group of aplite and porphyry dikes, which are the end products of Hercynian granitic intrusions. The dikes are 40 to 50 meters wide and cut metamorphic slate, diorite, gabbro, serpentine, and other rocks. Within the ore shoots that are found along the veins there are, in many places, concentrations of pyrargyrite, which result in an ore rich in gold (28 to 42 grams to the ton) and silver (110 to 375 grams to the ton). The average copper content of 5 to 8 percent gradually decreased with increasing depth (160–250 meters), and this was accompanied by an increase in the lead and zinc content. The length of the veins exceeds 100 meters, and the thickness is 1.5 to 2 meters.

The copper veins of Pyshminsko-Kluchevski are usually associated with pyritic copper lodes and are located along faults within uralitized porphyry. The porphyry is commonly found near the contacts between gabbro-diorites and bedded tuffs. There are 40 veins, of which 6 are of the most importance. The length of the veins is from 50 to 400 meters, the thickness from 0.3 to 1.5 meters, and the explored depth 80 to 100 meters. In addition to sulphides of copper and iron, the veins contain quartz, carbonates, and chlorite; the ore also contains apatite. The average copper content is 3 to 6 percent; the gold content is as much as 408 grams to the ton, and there is a high content of silver. In enriched parts of the vein the copper content is increased to 10 or 20 percent. Most of the veins are compound.

The veins of the Zangezur region, in Transcaucasia, are the most interesting from an industrial point of view. Although these deposits were worked by hand methods from the middle of the 19th century on, exploitation on a large scale began only in 1911. Altogether 35,000 tons of copper has been extracted from 250,000 tons of ore. The veins cut effusive porphyry or quartz porphyry and are covered by Jurassic limestones on the east. There are small hypabyssal intrusions of albitophyre, which is the probable source of the mineralization; dikes of diabase and porphyry are also found. The ores occur within a zone about 2 to 2½ kilometers wide and 5 kilometers long. Individual veins do not exceed 200 to 250 meters in length and are from 0.05 to 1.5 or even 5.6 meters wide. The average thickness is about 0.2 meter. The dip is steep (45° to 90°) and is generally toward the south. The veins have been studied for a depth of 150 meters. The oxidized zone ("marash") goes down 10 to 20 meters or more (40 to 50 meters). The vein filling consists of quartz, pyrite, and chalcopyrite, with which are commonly found bornite, tetrahedrite, and sphalerite. The zinc content in the group of veins averages about 10 to 12 percent and ranges from 4 to 18 percent; the average content of gold and silver is 0.005 percent. The developed copper reserves are now calculated at 98,000 tons, and there is an additional 85,000 tons of probable ore. The copper veins in the Caucasus, as well as those in other regions of the Soviet Union (eastern Siberia and the Far East), have scarcely been prospected.

Copper-bearing mixed sulphide deposits are found chiefly within the boundaries of Kazak Steppe, Altai, Central Asia, and the Caucasus. In Central Asia the deposits are commonly veins, but locally they occur in the form of metasomatic lodes (Kansai and others). The average copper content ranges from 0.5 to 2.5 percent; the lead content is about 2 to 3 percent; and the zinc content is from 1 to 5 percent or more.

The Buron deposits, in the Caucasus, were discovered in the neighborhood of the Sadonian mixed sulphide veins, which have an average copper content of less than 0.6 percent. The main ore lens of the Buron deposits contains chalcopyrite, arsenopyrite, sphalerite, and galena. The average copper content in the developed ore body is about 1.6 to 1.8 percent; the zinc content is about 3.5 percent, and the lead content 1.2 percent. A group of copper-zinc lodes is found in the Zangezur copper region. They have an average content of 2 to 5 percent of copper, with a zinc content of 15 percent and lead 2 percent. Many of the veins in Transcaucasia are of the mixed sulphide type, but the ore reserves are very small.

Impregnations.—The Djeskasgan type of lodes is characterized by sulphide impregnations (both massive and disseminated) in sandstone and closely resembles the deposits of central Africa (Katanga, Rhodesia). In 1915 about 61,000 tons of ore had been prospected with an average copper content of 10 to 12 percent. The prospecting carried on during the 4 years of the first 5-year plan increased this amount to 1,500,000 tons of copper in ores with an average content of 2.17 percent.

The mineralized area in the vicinity of the Djeskasgan deposits covers about 1,000 square kilometers and is underlain by a complex of sedimentary rocks of Devonian and Carboniferous age. The ore bodies occur commonly as gently dipping lodes (but locally as steeply dipping lodes) in the so-called "productive beds of Djeskasgan." The average thickness of the productive beds, which are in the central and upper parts of the Carboniferous, is 1,200 meters; a barren zone of red sandstones and slates, about 200 to 300 meters thick, overlies them. The mineralization was localized along overthrust faults, which generally strike northeast and are commonly marked by masses of quartz and by veins of barite and quartz. As yet, only 100 square kilometers out of the 400 to 500 square kilometers occupied by outcrops of the Djeskasgan beds has been surveyed, and an area of 1.5 square kilometers has been explored by drilling. This work has disclosed 37 ore bodies, of which 15 have been prospected.

The Taskura deposits, in the Golodnaia Steppe southeast of Djeskasgan, somewhat resemble those just described. In other parts of the Soviet Union this type of copper deposit appears to be of minor importance. In addition to the Taskura deposits, there are, in the Kazak Steppe, deposits in the Kokchetavski region and at the source of the Ishima River, in sandstones of probable Devonian age.

A few copper deposits in sandstone in the Minusinsky region (Pechinskoie, etc.) somewhat resemble the deposits of Djeskasgan. They occur in Devonian red beds.

The Djeskasgan type of deposit in the East Saiany region somewhat resembles the Fedorovskoie deposits on the river Uda. Here the bedded deposits, containing widely disseminated pyrite and chalcopyrite, are found in gently dipping beds of sandstone and quartzite.

Some of the deposits of the southern Tadjikistan possibly are of the Djeskasgan type. These deposits, however, are related to the Alpine epoch of mineralization.

Porphyry deposits.—The "porphyry copper" type of deposit has only recently become of prime importance in the copper industry of the Soviet Union, despite the fact that even before the World War individual deposits were known and were prospected in the Kazak Steppe (Koktas-Djartas).

The prospecting in 1927 of Koktas-Djartas and Koktas Kjala, in Kazakstan, was followed by the discovery of new and immense deposits of this type (Kounrad, Sokurskoi, Borly, Almaly, Boschekul, etc.); similar ore bodies were found in the Altai (Bukhtarminskoie) and in Central Asia (Almalyk, Balykhty, Sary-Choku, etc.). In the last few years additional deposits have been discovered and partly prospected in Transcaucasia (Agarak, Djindara, etc.), in the southern Ural region (Vosnesenskoie), and in southern Tadjikistan (Luch-ob). The prospected deposits of this type in the Soviet Union have reserves amounting to 7,900,000 tons of copper, out of the total of 15,800,000 tons that was determined at the end of the first 5-year plan.

The porphyry copper deposits in the Kounrad region (Prebalkhashstroi) are the best known and the most extensively developed. They were discovered in 1928. The commercial ores are thought to be genetically related to a silicified monzonite porphyry. In the central ore field, near Kounrad, which is about 650,000 square meters in area, the ore body is the result of supergene sulphide enrichment. The ores contain disseminated chalcopyrite and pyrite and have a gold and arsenic content of 0.035 percent. The hypogene sulphide impregnation has a copper content of 0.6 percent. The oxidized zone reaches a depth of 20 to 22 meters and has an average copper content of about 1.3 percent; the leached zone is 20 to 25 meters in thickness and contains 0.25 percent of copper; and the enriched zone extends to a depth of 200 meters or less. The average thickness of the commercial ores exceeds 110 meters; the average copper content is 1.11 percent, and the total reserves of copper are 1,450,000 tons.

The Borly deposit is 50 kilometers from Kounrad. A mineralized area of some 360,000 square meters is being prospected, and reserves of about 350,000 tons of copper have been determined.

The Boschekul deposits are 85 kilometers west of Ekisbastuas and about 200 kilometers from the Irtysh River. Prospecting was started here in 1930. The mineralized area lies in a region of lower Paleozoic effusive and sedimentary rocks; small islands of Carboniferous rocks occur a short distance to the west. The bedded rocks are cut by a branching dike of granite porphyry, which is more than 6 kilometers in length, with a strike of N. 55° E., and which has a width of as much as 500 meters. The ores are found both in the dike and in porphyries and sandstone of Silurian age along their contacts with the dike. The mineralized area exceeds 1.5 square kilometers. The zone of enriched sulphide ores extends from a depth of 12 or 15 meters down to 70 to 75 meters, having an average thickness of 60 meters.

Out of 60 deposits known in the Koktas-Djartasski region, not less than 8 or 10 are of the porphyry copper type (Koktas-Djartas, Koktas-Dkal, Malik-Kainar, Djusaly, etc.). These deposits are not large but have rather rich ores (1 to 2.3 percent of copper).

Although there are at least 100 different kinds of copper deposits in Central Asia, the porphyry copper deposits have proved to be of most importance. The porphyry copper deposits in the Almalyk region, 90 kilometers southeast of Tashkent, are relatively few but are large. They are now being prospected. Ten deposits of this type have already been discovered (Almalyk, Balykhty, Sary-Choku, etc.), and the possibility of discovering still others is believed to be good. The geologic structure of the Almalyk region closely resembles that found at Kounrad. The mineralized area that has been prospected covers 9.87 square kilometers. The oxidized ores have an area in plan of 0.37 square kilometer and a maximum depth of 70 meters. Their thickness averages 19 meters and ranges from 4 to 44 meters. The thickness of mixed ores is 11 meters. The chalcocite zone is reached at depths of 28 to 70 meters. The ore bodies, which have been developed over an area of at least 0.6 square kilometer, are almost horizontal except for local swells. The hypogene sulphide ore underlies an area 1 kilometer in length and 200 to 400 meters in width. The average thickness of the ore bodies is about 70 meters; the maximum thickness 180 meters. The ore bodies so far developed have an area in plan of about 0.34 square kilometer; and further work is expected to increase this figure to 0.5 square kilometer. A large fault passes through the deposit, dividing it into two parts, called "large Kalmakyr" and "small Kalmakyr." The fault is clearly shown both by the depth to the ore and by the mineral composition. The copper content in the oxidized ores averages 1.1 to 1.2 percent (ranging from 0.5 to 3 percent); in the rocks of the leached zone, 0.2 to 0.25 percent; in the zone of enrichment, 1 percent (ranging from 0.6 to 2 percent); and in the hypogene sulphide impregnations, 0.7 percent.

The porphyry copper ores in Tadjikistan have only recently been discovered and have not yet been prospected.

The Transcaucasian porphyry copper deposits (Agarak and others) are of Alpine age. The ore bodies are localized along a zone of deformation and are within the Megrinski intrusive massif, in places where there are small granodioritic intrusions. The zone of secondarily enriched ores is poorly developed as a result of strong relief due to rapid erosion. The reserves of copper are calculated, on the basis of the Agarak deposit, at 575,000 tons, and of molybdenum at more than 15,000 tons. A group of deposits similar to those at Agarak is much smaller.

Disseminated ores are found in the gabbro massifs of the central Ural Mountains. Prospecting here has shown ore bodies with a copper content of 0.85 percent at a depth of 70 meters. The reserves for the region are estimated to be 190,000 tons of copper.

Sedimentary deposits

The copper-bearing sandstones of the Pre-Ural region are the best-known examples of this type of deposit. They were discovered in 1700, and exploitation started in 1728. Since that time 240,000 tons of copper has been extracted from them, in spite of the fact that the average thickness of the copper-bearing bed is only 0.15 meter. The copper-bearing sandstones of the western Pre-Ural region are located in a belt 1,000 kilometers long and 30 to 150 kilometers wide. The beds are considered to be a part of the red conglomerate and sandstone zone of the Permian system. The ore bodies occur as isolated lenses, nests, ribbons, etc., which have a random distribution in both plan and section. The maximum depth to the ore bodies is 72 meters; the average depth ranges from 11 to 23 meters. The usual length of commercial ore bodies is 60 to 200 meters (in exceptional deposits 1 or even 3 kilometers); the width ranges from 10 to 80 meters (locally 100 to 400 meters); and the thickness averages from 0.1 to 0.4 meter (ranging from 0.04 to 2 meters or more). The copper content is from 0.4 to 15 percent, averaging 2 to 2.5 percent. The reserves of copper so far determined aggregate about 280,000 tons. Of this amount, about 60,000 tons is in a district in the southern Ural Mountains that has been investigated in detail. The average copper content here is 1.5 to 1.9 percent.

The copper-bearing sandstones of the Don Basin are also believed to be of the same age as the Permian sediments in which they occur. They closely resemble the Ural deposits, but the individual deposits are considerably smaller, the largest being 70 meters long, 15 meters wide, and 2 meters thick.

Sedimentary copper deposits are widely distributed in the Lena region of eastern Siberia. Two ore-bearing sandstones have been found in Silurian red beds, one having a thickness of 0.5 to 1 meter, the other of 5 meters or less. The average copper content is 1.5 to 2 percent. The occurrence of these two sandstones along the Lena River for a distance of 500 kilometers has caused considerable prospecting in the region.

Copper-bearing sandstones, which are associated with limestones, have been discovered recently in Central Asia—in the Altai Ridge and in the mountains of southern Tadjikistan.

The Naukatskie deposits of native copper in the Tertiary Arkozovy sandstones were first worked at the beginning of the 20th century. There are seven ore-bearing zones, each of which has a thickness of 0.5 to 3 meters and which extend for a distance of 20 kilometers along the Syr Darya. The average copper content in the ores is from 0.27 to 0.45 percent.

ASIA

The copper deposits of China

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Introduction

In broad terms the copper deposits of China occur in five mineralized regions—namely, the Yangtze Valley, the southeastern coast, in and north of the Tsinlin, Kirin and Liaoning, and Sinkiang. (See pl. 38.) I classify them into six genetic types—(1) pneumatolytic, (2) contact-metamorphic, (3) hypothermal, (4) mesothermal, (5) deposits in basic lava, and (6) sedimentary. The pneumatolytic type includes the famous deposits of Tungchuan, in eastern Yunnan, and of Huili, in southwestern Szechuan. They are in genetic relation with gabbro masses, and the ore minerals are usually associated with tourmaline. The contact-metamorphic deposits occur in the lower Yangtze Valley and Kirin Province, mostly at the contact of dioritic rocks and limestones and subordinately at the contact of granites or porphyries and sandstones. The hypothermal deposits include the pyrrhotite-chalcopyrite veins of Penghsien, southwestern Szechuan, and of Tsinan, Shantung, and the bornite-chalcopyrite veins of Nanping, Fukien. These deposits occur in metamorphosed rocks. The mesothermal deposits are found in all the mineralized regions in veins or pockets or disseminated in the limestone or metamorphosed rocks. Copper deposits occur in basic lava in southwestern Szechuan, eastern Yunnan, and western Kueichou in the upper Yangtze Valley. The Permian basic lava generally contains copper-bearing minerals disseminated or filling the vesicles, or in veins in the fissures or cracks or at the contact of the lava and limestone. Post-Permian or Triassic sedimentary copper-bearing beds are exposed in southwestern Szechuan and eastern Yunnan, immediately overlying the Permian basic lava, which is probably the source of the copper deposits. The ores form nodules or replace wood in veinlets or occupy fissures in sedimentary rocks. Copper-bearing minerals scattered in sandstone and shale in western Sinkiang are said to be also of this type.

Much information on Chinese copper deposits is contained in W. H. Wong's memoir on China's mineral resources (1). This memoir is yet little known abroad, because it was published in the Chinese language. A good scientific paper was written by C. Y. Hsieh (2), who paid special attention to the copper deposits in southeastern Hupeh, eastern Yunnan, and southwestern Szechuan and discussed their genesis and paragenesis. H. C. T'an and C. Y. Lee (3) surveyed the copper deposits in Szechuan and Hsikang, and their collections were investigated microscopically by me (12). Recently, in company with C. Shih and Y. S. Chi, I made a survey in eastern Hupeh, southeastern Shansi, and northwestern Honan. At the end of last year Y. H. Hsiung and I made a geologic survey in northwestern Hupeh. All these investigations have been utilized in preparing the present paper.

Copper mining and smelting are still little developed in China. The largest production of metallic copper, a few hundred tons a year, comes from Yunnan. Other provinces, such as Szechuan, Sinkiang, and Kirin, each have a much smaller output, not even enough for local consumption.

I have endeavored throughout this paper to give full acknowledgment both to the authorities quoted and to the organizations that published the original papers. I wish especially, however, to express my sincere gratitude to Dr. W. H. Wong, Director of the National Geological Survey of China; Prof. C. Y. Hsieh, China Foundation research professor; and Prof. H. H. Chen, of the National Central University, for their valuable advice and criticism.

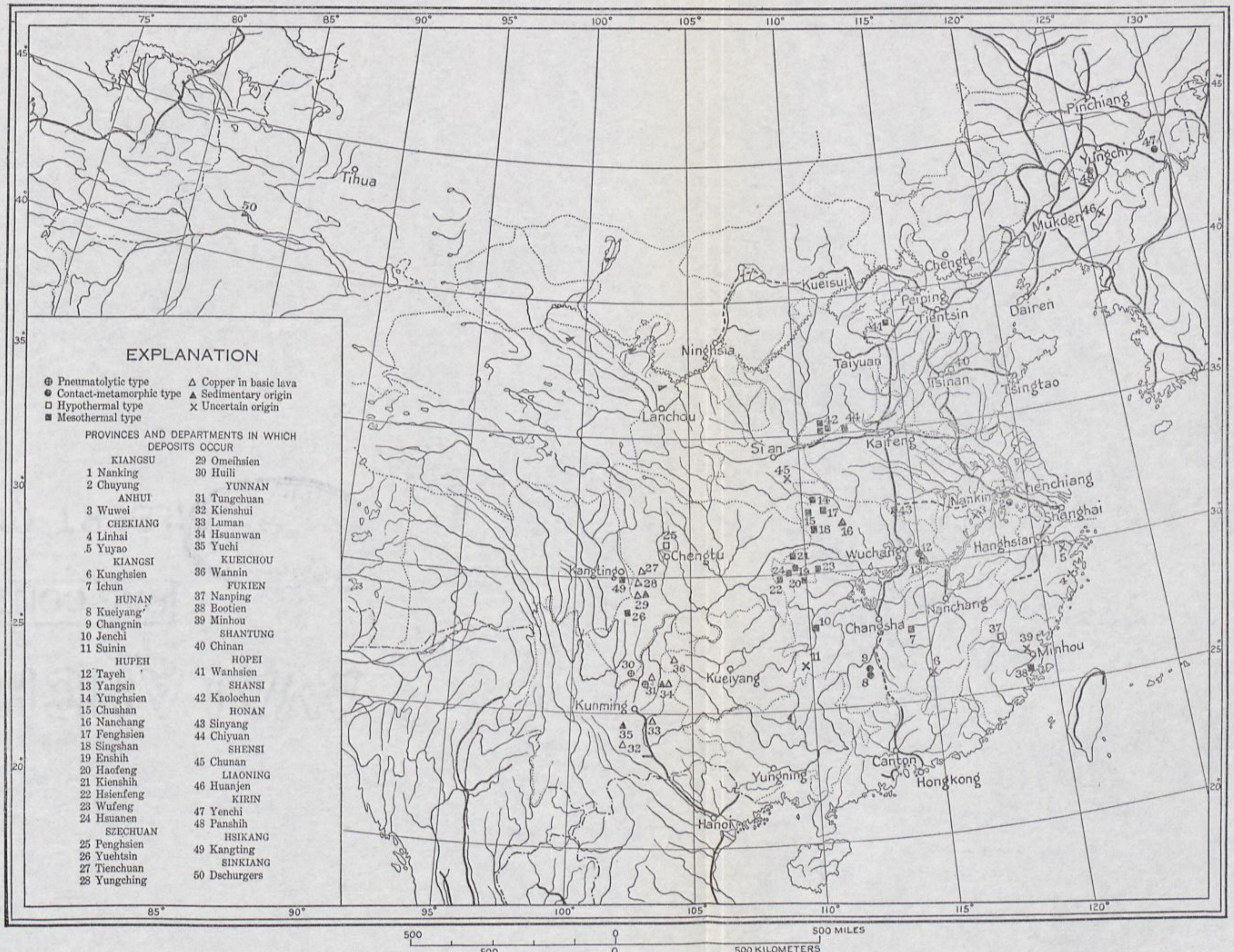
Pneumatolytic type

Tungchuan, Yunnan

One of the earliest geologic works on Chinese copper deposits is that by V. K. Ting on the famous Tungchuan copper mines (4), which have been worked since 1697 and produced in the 18th century several thousand tons of copper annually. The mines are in the northeastern part of Yunnan, near the common boundaries of Yunnan, Szechuan, and Kueichou. They occur in five principal localities—Tandan, Loshue, Tashui, Moulu, and Tiechang. Except Tiechang, which is west of the upper Yangtze River near the Szechuan border, these groups are between the Yangtze and its tributary the Hsiaokiang, southwest of the city of Tungchuan. (See fig. 102.)

Yunnan and Szechuan are separated by the Launshan Range, which runs north-northeastward and has a steep escarpment on the east side. The highest part of the range consists of Permian and Upper Carboniferous limestone underlain by sandstone, clay, and limestone of Carboniferous age. Farther east, toward the Yangtze, numerous faults occur, and the rocks are more metamorphosed. Scattered in these metamorphosed Paleozoic sediments, chiefly in the limestone, are numerous irregular bodies of copper sulphides, mainly chalcopyrite. This metallogenic region is limited on the south by a massive range, the Tashueshan, which runs west-northwestward. Within the metallogenic zone there are several gabbro intrusions, which are no doubt in genetic relation with copper deposits.

The deposits occur either in metamorphosed sandstone and shale or in Carboniferous limestone. About 80 percent of the ore now worked comes from the limestone, including that in the three principal centers Tandan, Loshue, and Tashui. The deposit at Tandan is an irregular stockwork with a few concretionary masses of barite. One body ranges from 10 centimeters to 1.5 meters in width, with 60 centimeters as an average. The primary ore is chalcopyrite, which is in places altered to carbonate, with a gangue of quartz, calcite, and siderite. Tandan is one of the most productive mines and yields more than 45 percent of the total copper produced in Tungchuan. At present mining seems to be almost



MAP SHOWING GEOGRAPHIC DISTRIBUTION OF DIFFERENT TYPES OF COPPER DEPOSITS IN CHINA

entirely confined to the oxidized zone, which extends to depths of 15 to 25 meters. In Loshue and Tashui the ore occurs in irregular masses ranging from a few decimeters to more than 1 meter in width. The ore minerals are chiefly bornite and chalcocite, and in places the deposits are extremely rich. Tiechang and Moulu contain disseminated ore in the metamorphosed beds.

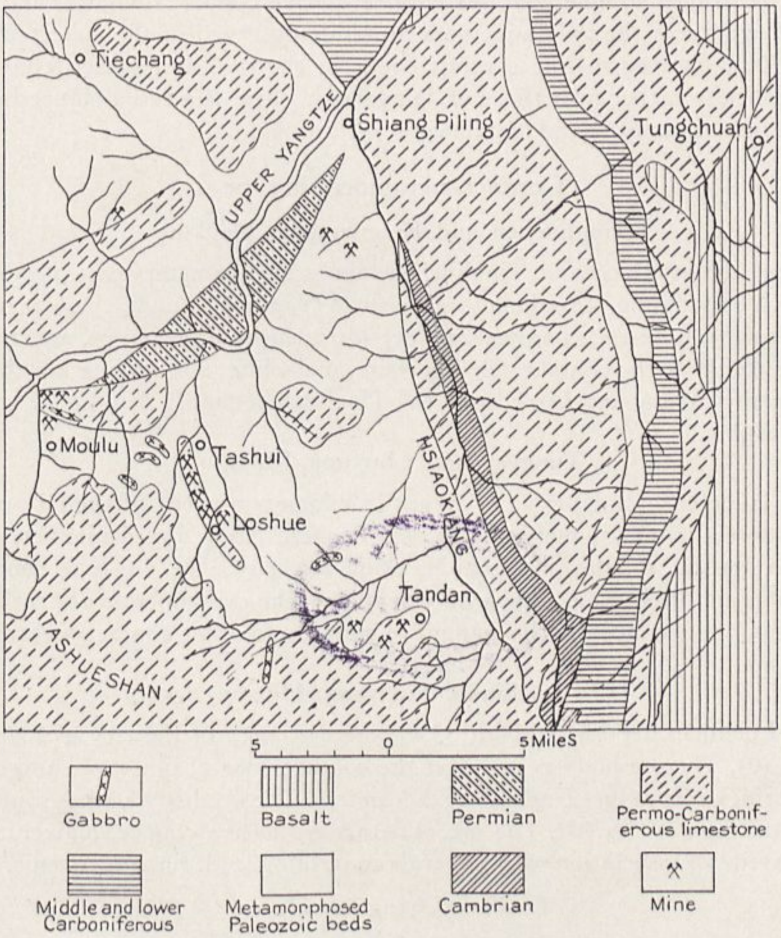


FIGURE 102.—Geologic sketch map of the area containing the Tungchuan copper mines, Yunnan, China. (After V. K. Ting.)

The general sequence of the primary minerals beginning from the oldest, as pointed out by Hsieh, is as follows: Tourmaline and quartz, chlorite, pyrite, bornite, chalcopyrite, hypogene chalcocite, and hematite. He also believed that these deposits perhaps belong to the pneumatolytic type.

Huili, Szechuan

Copper deposits occur in the southern part of the Huili district, southwestern Szechuan, at Luchang and Tungan (2, pp. 295–299). At Tienpaoshan, Luchang, the Permian sandstone beds contain a gabbro intrusion, and copper sulphides occur in the contact zone. The ores as worked average 3 to 4 percent of copper. At Tungan copper ores occur in metamorphosed sandstone more distant from the contact zone. The average copper content is about 10 percent.

Hsieh states that the primary ore consists of pyrite, sphalerite, tetrahedrite, galena, chalcopyrite, and saffeorite, named in their approximate order of deposition. The oxidation zone contains cuprite, native copper, limonite, and malachite. Covellite is the only supergene sulphide observed in the collected specimens. As a few tourmaline crystals occur in the ore, and these deposits are geographically rather near those of Tungchuan, there is a resemblance between the two in both geologic and metallogenic conditions.

Contact-metamorphic type

Tinglinchen and Kuantzetung, Nanking

Copper deposits occur at Tinglinchen, about 10 kilometers east of Nanking, and at Kuantzetung, 45 kilometers south of Nanking (5). At these places the Jurassic sandstone and conglomerate are intruded by a porphyry, and the copper ore occurs at the contact. Chalcopyrite, malachite, and azurite are the chief ore minerals. Wang and Lee classed the Tinglinchen copper deposits as contact-metamorphic.

Tungyehshan, Chuyung, Kiangsu

The Tungyehshan deposit lies about 25 kilometers north of the city of Chuyung, more than 5 kilometers from the Yangtze River and 5 kilometers from Hsiashu station, on the Shanghai-Nanking Railway. The ore is in sandstone, quartzite, and limestone, near a dioritic mass. The ore minerals are carbonates and sulphides of copper, with a gangue of garnet and other contact-metamorphic minerals.

Luchihao, Kueiyang, Hunan

The Luchihao deposit is about 55 kilometers north of the city of Kueiyang, Hunan (6). The ore body is found at the contact zone of limestone and diorite, and its thickness ranges from 1.6 to 3.3 meters. The ore body strikes southwestward and dips 30° to 40°. The ore minerals are native copper, malachite, and chalcopyrite in association with minerals containing lead, tin, and arsenic.

Taishan, Changnin, Hunan

The ore deposits at Taishan, in Changnin, near Kueiyang (6), Hunan, are in limestone intruded by a granitic rock. One of them about 40 kilometers south of the well-known Shuikoushan zinc mines is about 10 centimeters in width. The ore minerals are chalcopyrite, bornite, and arsenopyrite. The tenor is said to be 30 percent of copper and 0.0003 percent of gold.

Tayeh and Yangsin, Hupeh

Copper in irregular replacement bodies or veinlike forms is widely distributed in Tayeh and Yangsin, in southeastern Hupeh (2, pp. 264–282; 7). (See fig. 103.) In this region there is a series of sedimentary rocks ranging from Silurian to Jurassic in age. Granodiorite intrudes both Permian and Triassic limestone and Silurian sandstone and shale. The ore deposits occur mostly at the contact between the limestone and granodiorite, but also exclusively in limestone. A well-defined contact zone of solid garnet with some pyroxene and amphibole is present in most of the deposits. Copper deposits are known in the following districts, and some of them have been prospected.

At Niutoushan, about 2 kilometers southeast of Peishapu, one of the principal villages of the Yangsin district, copper ores, chiefly bornite and chalcopyrite, are found in a contact zone between limestone and diorite. The contact trends approximately southwest. The contact-metamorphic zone continues from Niutoushan toward the northeast and then northwest as far as Liuhsushan and Hanchiashan and is about 15 kilometers or more in total length.

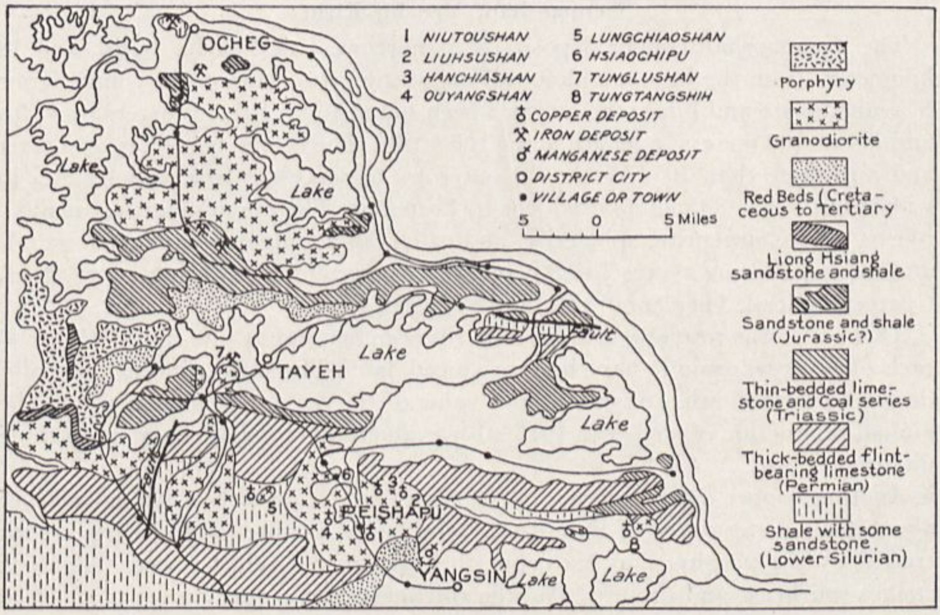


FIGURE 103.—Geologic sketch map of the area containing the Tayeh and Yangsin copper deposits, Hupeh, China. (After Hsieh and Liu.)

The Liuhsushan deposit is about 5 kilometers northeast of Peishapu, on the slope of Chihmashan, a lofty mountain composed chiefly of Permian limestone. Granodiorite crops out on the western foothills of the mountain. At the contact between the limestone and the diorite occurs a northwestward-trending garnet zone 6 to 8 meters wide. Chalcopyrite with abundant specularite and magnetite is scattered in the garnet rock, which is also accompanied by actinolite, albite, zeolite, and amphiboles.

From Liuhsushan the contact zone continues a few kilometers farther to the northwest and forms there the copper deposits of Lichiashan and Hanchiashan.

The deposit at Ouyangshan, about 2 kilometers west of Peishapu, is almost entirely confined to the limestone. The ore is said to be rich and consists of bornite, chalcopyrite, chalcocite, malachite, and azurite in association with quartz, calcite, garnet, and some other minerals.

At Lungchiaoshan, a high and steep hill lying about 13 kilometers northwest of Peishapu and rising about 500 meters above the adjacent valley, much pyrite associated with bornite and chalcopyrite occupies pockets in the limestone.

Almost every one of these deposits is accompanied by contact-metamorphic minerals, such as garnet, wollastonite, tremolite, actinolite, and diopside. The ore minerals are pyrite, magnetite, hematite, bornite, chalcopyrite, chalcocite, covellite, and malachite.

Hsieh recognizes two types of deposits in this region—the contact-metamorphic deposits of Liuhsushan, Niutoushan, and Tientaishan and the hydrothermal replacement deposits of Ouyangshan and Lungchiaoshan.

Tienpaoshan, Yenchi, Kirin

The Tienpaoshan copper deposit (8) is northwest of Yenchi, Kirin, and 18 kilometers from the Laotouerhkou railway station. It occurs in the contact zone of granodiorite and limestone and has been found to be 1 to 15 meters in width and about 100 meters in length along the strike. The ore body strikes southeast and dips more than 70° SW. At the outcrop the deposit is less than 1 meter in width, but below 80 meters it widens to 17 meters. The ore minerals are chalcopyrite, pyrite, argentite, sphalerite, and galena in a gangue of contact minerals and calcite. The ore assays 7 to 8 percent of copper, 0.5 to 0.03 percent of silver, 6 percent of lead, 3 percent of zinc, and a trace of gold.

This place was formerly famous as a silver mine, and at one time 700 to 800 taels of silver was said to have been produced daily. The silver content gradually decreased with depth, and the copper value of the deposit was recognized. The annual production of copper in 1916–21 was about 300 tons, with an appreciable quantity of lead.

Another copper deposit occurs in the same district near the Chaoyang River about 1 kilometer north of Pataokou. Here gneiss, granite, and phyllite are intruded by the porphyry, and a copper-bearing quartz vein has been found. It strikes southeast and dips 56° W. The thickness of the vein ranges from 15 to 60 centimeters. Pyrite and chalcopyrite are the chief ore minerals.

Shihtziushan, Panshih, Kirin

The Shihtziushan copper deposit lies 17 kilometers north of Panshih. In this region limestone is intruded by granodiorite. The ore body forms an eastward-trending vein at the contact zone, with abundant garnet. It is about 500 meters long and about 1 meter wide. The ore minerals are pyrite, chalcopyrite, bornite, chalcocite, cuprite, azurite, and malachite, in a gangue of quartz, fluorite, calcite, and garnet. The copper content is said to be 10 to 30 percent. This deposit was mined by the Kirin Provincial Mining Administration in 1908–18 and produced about 200 tons of copper each year.

A similar copper deposit is reported about 5 kilometers southeast of the same district, at Chitzeshan, but no other information concerning it is available.

Hypothermal type

Penghsien, Szechuan

The productive deposits of Penghsien are north of the village of Paishuiho, about 45 kilometers northwest of the city of Penghsien and 90 kilometers from

Chengtu, the capital of Szechuan. In this region a series of sedimentary rocks ranging from Permian to Quaternary in age overlie the pre-Cambrian Paishuiho metamorphosed series. At Tungchangpo, southwest of this region, many granite boulders occur in the streams. Copper ores have been found in many places, such as Masungling, Huatitzu, Panchiehho, Michiashan, Hoshangshan, Tungchangpo, and Paokuangtung. All these deposits are in schists and crystalline limestone of the Paishuiho series.

At Masungling the copper deposit is a vein in mica schist. It is 1 to 6 meters thick and probably over 600 meters long. The vein strikes north-northwest and dips about 30°–40° NE.

At Huatitzu the copper-bearing minerals have been found in a pyrrhotite vein in chlorite and mica schists. The strike of the vein is almost concordant with that of the schists. The thickness of the vein ranges from 40 centimeters to 1 meter, but its length is not known.

At Panchiehho the copper-bearing vein is in sericite schist and strikes nearly parallel to the schist and dips about 40° ENE. This vein is about 2 meters thick and about 50 meters long on the surface.

At Hoshangshan an irregular vein about 1 meter thick occurs in muscovite and sericite schists.

In Michiashan there are some small and thin quartz-pyrite-chalcopyrite veins in sericite, talc, and chlorite schists. No good ore has yet been found. Tungchangpo and Paokuangtung are known by old mines, now abandoned.

From microscopic investigations I have found that the ore minerals in these veins are pyrrhotite, pyrite, tetrahedrite, and chalcopyrite, with small amounts of sphalerite, galena, and chalcocite. Pyrrhotite is the most abundant mineral. Oxidized products of copper-bearing minerals, such as covellite, azurite, malachite, melaconite, and native copper, have also been recognized. The gangue minerals are quartz, calcite, and hornblende, the hornblende mostly altered to chlorite. Sericitization, chloritization, carbonatization, and silicification have altered the wall rocks. The silicates and carbonate are generally later than the sulphides, but the periods of deposition usually overlap. The order of hypogene sulphides begins with pyrite, followed by pyrrhotite, sphalerite, chalcopyrite and tetrahedrite, and galena. The supergene chalcocite, covellite, pyrite, carbonate and oxides of copper- and iron-bearing minerals are the latest minerals formed by the processes of enrichment and oxidation.

T'an and I believe that these deposits have been formed during a period of general mineralization and have had a common hydrothermal origin in close genetic relation with the granitic intrusion underneath the copper-bearing Paishuiho series. From the presence of pyrrhotite, hornblende, etc., these deposits are concluded to be of hypothermal origin.

Tsaotou, Nanping, Fukien

Copper-bearing quartz veins occur southeast of the city of Nanping, Fukien, and on the south bank of the Min River (10). They are in a metamorphosed series intruded by quartz porphyry. The thickness of the veins ranges from a few decimeters to more than 3 meters. The longest one, near Tsaotou, extends 1,330 meters. Prospecting has reached a depth of 60 meters following the dip of the vein but has not yet gone through the leached zone. The ore consists chiefly of bornite with subordinate chalcopyrite, malachite, and azurite. It contains 14 to 19 percent of copper, with 20 ounces of silver to the ton and a trace of gold. T'an and Wang classified these veins as of hypothermal origin.

Taokochung, Tsinan, Shantung

The Taokochung copper deposit is about 50 kilometers southeast of Tsinan, the capital of Shantung. In this region the rock is chiefly gneiss and the ore minerals are pyrrhotite, pyrite, chalcopyrite, and pentlandite.

Mesothermal type

Chingjui, Ichun, Kiangsi

Copper deposits occur about 7.5 kilometers northeast of Chingjui, which is northwest of Ichun, western Kiangsi. They are exposed at Wuchiachienfeng, Tingshan, Leitashan, and other places and consist of copper-bearing quartz veins in limestone, with granitic intrusions nearby. The veins are about 10 centimeters thick, and the ore is said to carry from 3 to 7 percent of copper.

Tungchungman, Jenchi, Hunan

The copper deposit 10 kilometers west of Jenchi, Hunan (6), was formerly mined by the Paoli Mining Co. and in 1916 by the Provincial Mining Administration. The mines are now abandoned. The ore body is in limestone, and its chief ore minerals are chalcopyrite, pyrite, and malachite.

Northwestern Hupeh

Chushan.—Copper deposits occur from 55 to 75 kilometers west and northwest of the city of Chushan in northwestern Hupeh. Many old mining places in this region were known, such as Denchiashan, Chenchiashan, Lianchiapa, Kuochiakou, Chengchiashan, Liuchiashan, Jenhsienchu, Ssuhoshu, and Yenhokou. The ore bodies are veins in limestone and quartzite (7) and occur mostly in the fault fissures. The ore minerals are chalcopyrite, malachite, azurite, and cuprite, with native copper particularly abundant in the old and shallow mines.

Shihjenho.—Deposits like those in Chushan are found at Shihjenho, west of the city of Yunshien (7). The vein is in mica schist, strikes northeast, and dips 52° SE. It is about 12 centimeters thick. The ore minerals are bornite, chalcopyrite, and malachite.

Western and southwestern Hupeh

Fenghsien.—Copper deposits occur at Hsiaotsinkou, T'ungtungkou, and Tierhyen, between 225 and 250 kilometers west of Fenghsien. All these deposits form veins a few centimeters thick in the limestone. The ore minerals are chiefly chalcopyrite and some oxidized products.

Shihtsaoho.—At Shihtsaoho, about 80 kilometers from the city of Singshan, copper ore forms pockets in gray limestone and has been reported to be of fairly high grade.

Shatzuling.—In a deposit at Shatzuling, about 35 kilometers southeast of the city of Enshih, the ore forms pockets in limestone and was unsuccessfully mined in the later years of the last dynasty.

Haofeng.—Copper deposits are present at Chowtaishan, Tangchiapo, Hungchuntung, and elsewhere about 100 kilometers southeast of Haofeng. The ore bodies occur in limestone. The deposit at Chowtaishan was mined in the later years of the last dynasty and produced more than 5,000 catties of crude copper, but the mines were soon afterward shut down.

Tungchangpo.—The Tungchangpo deposit, which produced an appreciable quantity of copper in the 17th century, is about 7 kilometers north of Kienshih. The country rock is limestone.

Tingchai.—The deposit at Yuanchiakou (11), more than 2 kilometers southwest of Tingchai, which is 15 kilometers southwest of Hsienfeng, was once worked in the later decades of the 19th century, with an annual production of several hundred thousand catties. In 1912 this deposit was reopened, and in 1915 it was worked by the Tingsing Co., which produced an appreciable quantity of copper. The mine was finally abandoned in 1918. The copper ore consists of chalcocite, bornite, chalcopyrite, and some azurite. These deposits form irregular pockets in Ordovician siliceous and brecciated limestone.

Wufeng.—Copper ores have been found at Chiehtoupao, about 25 kilometers south of Wufeng, and at Chouchiapao, about 45 kilometers southwest of that city. The ore bodies are in limestone and were mined in the last dynasty.

Hsuanen.—Copper ores have been found in the southern part of the Hsuanen district, at Laoyehtsun, Tashanping, Ichialing, and Jentoushan. The Laoyehtsun deposit lies about 75 kilometers southeast of the city of Hsuanen. The ore forms a vein about 1 meter thick in limestone. The vein strikes N. 20° E. and dips 10° SE. In 1912 it was mined for a short time. The Tashanping and Ichialing deposits are about 40 kilometers southwest of Hsuanen. They were formerly mined and smelted by native methods but were finally abandoned because of the troubles of transportation and water. The Jentoushan deposit, south of Hsuanen, is not yet mined.

Anshunchang, Yuehtsin, Szechuan

Copper deposits occur west of Anshunchang and northwest of Yuehtsin, in southwestern Szechuan (12). At present the ores are mined by the Tienyu Copper Mining Co. at Lienhuatung, Chifenyao, and Hunghuangchientzu. (See fig. 104.) In this region the Jurassic and younger sediments overlie the Chihsia limestone, of Permian age. The veins occur in the limestone. At Lienhuatung the vein strikes east and dips 10°–30° N. and ranges from 10 centimeters to 1 meter in thickness. It consists chiefly of massive tennantite with subordinate chalcopyrite, pyrite, sphalerite, bornite, and enargite with a gangue of quartz and calcite. The deposits were mined till 1931 to a depth of about 66 meters along the vein. No change of mineral composition has been recognized. Chifenyao is one of the old mines, where the geology and mineralogy are similar to those of Lienhuatung, but the vein is only a few decimeters thick. At Hunghuangchientzu, on the west bank of the stream, only the gossan has been mined by the same company for fluxing the copper ore.

The wall-rock limestone is mostly recrystallized as calcite in association with epidote and chlorite. Grossularite is present, with cracks or interstices filled up by tennantite, chlorite, and calcite. Quartz was deposited from the time of deposition of garnet to the end of the sulphide deposition. In the specimens collected from Hunghuangchientzu the residual fragments of chalcopyrite are mostly replaced by chalcocite, and several proustite crystals in association with quartz were recognized. The sequence of hypogene sulphides, in order of age, is magnetite, pyrite, sphalerite, chalcopyrite, bornite, enargite, and tennantite.

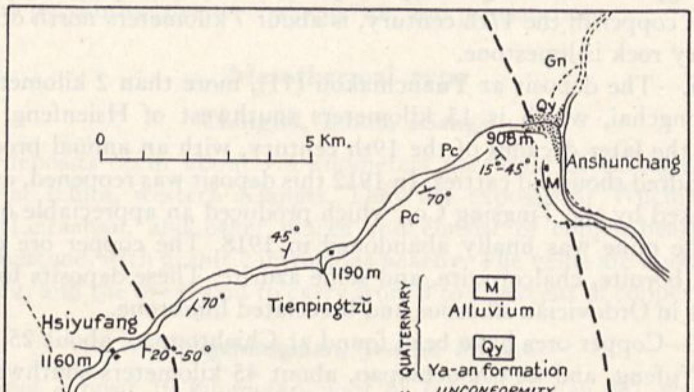


FIGURE 104.—Geologic sketch map of the area containing the copper deposits of Anshunchang, Szechuan, China. (After T'an and Lee.)

Yinkengshan, Putien, Fukien

At the copper deposit about 25 kilometers north of Putien, Fukien, the ore veins, about 1 meter thick, occur in gneiss and quartzite. The ore minerals are chalcopyrite, magnetite, galena, and pyrite with some silver minerals and gangue quartz.

Hanyangpo, Wanhsien, Hopei

A small copper deposit occurs at Hanyangpo, Hopei, 22 kilometers north of Wanhsien and 10 kilometers from Fengshunchiao station on the Peiping-Hankow Railway. The ore vein occurs in Cambrian limestone; it strikes N. 70° E. and dips 60° SE. The vein is about 4 to 8 centimeters thick. The ore minerals are bornite and malachite in a gangue of calcite and quartz. The ore contains about 39 percent of copper, 1.8 percent of iron, and 29 percent of silica.

Kaolochun, Shansi

Copper deposits occur near the center of Kaolochun, near the common boundaries of the Wenhsi, Yuanchu, and Chianghsien districts, in the southwest corner of Shansi (7). The chief ore deposits are distributed in Pitzukou, Liuchungyeh, Paotzukou, Hsiyanghui, and Tungwakou. The first two places are about 50 kilometers northeast of the city of Wenhsi and 10 kilometers west or north from Kaolochun; Paotzukou is northwest of Yuanchu and 15 kilometers northeast of Kaolochun; Hsiyangkou and Tungwakou are in the eastern part of Chianghsien more than 20 kilometers north of Kaolochun. The deposits at Pitzukou and Paotzukou were mined in the 7th century.

In this region the rocks exposed consist of the Wutai metamorphic series, and igneous rocks are lacking. The rock section at Pitzukou is shown in descending order as follows:

	Meters
Massive pinkish quartzite	350
Dark-gray thin-bedded quartzite	100
Dull-gray quartzite with copper ores	200
Black mica schist and phyllite	50
Marble	100
Chlorite schist and dark-gray marble	25
Quartzite	30
Schist and slate	35
Dark-gray quartzite	25
Mica schist	25
Massive garnet rock	35
Black quartzite	20

The copper ores occur chiefly in the dull-gray quartzite, but some copper-bearing minerals are disseminated in the garnet rock. The ores are mostly disseminated, but some form thin veins in the quartzite. The ore minerals are magnetite, pyrite, chalcopyrite, and chalcocite, with some oxidation products such as melaconite, malachite, and cuprite. The altered rocks contain chiefly sericite, recrystallized quartz, chlorite and some hornblende, biotite, and feldspars. The feldspars and biotite are mostly converted into sericite and chlorite, with a pseudomorphic structure.

Chiyuan, Honan

The copper deposits northwest of Chiyuan, in northwestern Honan (7, 13) north of the Hwang Ho, are known from more than 17 places in an area 15 kilometers from north to south and 25 kilometers from east to west. The basal strata in this region consist of Wutai metamorphic rocks overlain by Cambrian, Ordovician, and Permo-Carboniferous formations. The Wutai rocks include gneiss, schist, marble, and quartzite. The copper ores occur chiefly in small and scattered quartz veins or disseminated in these rocks, but some veins also occur in the Cambro-Ordovician limestone. Some of the veins are concordant in strike with the wall rocks, but most of them are distributed in a network. The thickness of the larger veins ranges from less than half a meter to a few meters and their length from a few meters to 100 meters.

Microscopic examination shows that the fine-grained chalcopyrite and magnetite are disseminated in the rocks, and the massive chalcopyrite is mostly converted to chalcocite, malachite, cuprite, native copper, and copper pitch ore, in association with limonite. Some grains of rutile, pyrite, and pyrargyrite are recognized in polished sections. The altered rocks show sericite, recrystallized quartz, chlorite, and leucoxene with some grains of biotite, muscovite, and feldspars. The feldspars and micas are mostly altered to sericite showing pseudomorphic structure. I believe that these disseminated deposits and small veins have been formed during one period of general mineralization and have had a common mesothermal origin.

Chutsungling, Sinyang, Honan

There is a small copper deposit at Chutsungling, southeast of Sinyang, Honan, 11 kilometers east-northeast of the small station Liulin on the Peiping-Hankow Railway. The vein has well-defined walls, a thickness of 2 to 3 meters, and a length of about 500 meters. It is nearly vertical in the pre-Cambrian or Paleozoic gray shale. The strike of the vein is concordant with that of the shale—S. 25° E. The vein is filled by quartz, fragments of shale, and malachite, but rarely copper sulphides. The ore is said to contain 2.56 percent of copper.

Kangting, Hsikang, Tibet

The copper deposits north of Kangting, in Hsikang, eastern Tibet, consist of quartz veins in limestone (3). Both the veins and the limestone strike northeastward. The vein exposed on Tengchanwo is about 30 centimeters thick and extends over 200 meters, but that on Pienyentzu is only a few decimeters thick. The shallowest part of the veins was formerly mined for gold. Under the microscope I found that the ore minerals are pyrite, tetrahedrite, chalcopyrite, bornite, and native gold. The native gold is usually associated with pyrite grains. Chalcocite has replaced chalcopyrite, bornite, and tetrahedrite, either in the form of veinlets or along the borders of their grains. Covellite has replaced chalcocite only; malachite and azurite have replaced all the copper-bearing minerals. The order of deposition of the hypogene minerals, beginning from the oldest, is pyrite, native gold, chalcopyrite, bornite, and tetrahedrite. The gangue minerals are chiefly quartz and calcite.

Copper deposits in basic lava

Tienchuan, Szechuan

The Permian basaltic lava is widely distributed and well exposed here and there in the southwestern part of Szechuan and extends to the northern part of Yunnan and the western part of Kueichou. The basaltic rock generally contains small amounts of copper-bearing minerals, which I have recognized from specimens collected by T'an and Lee from Chinchuling, north of Yungching, and the northern part of Tienchuan.

The ores are of too low grade for the Chinese method of smelting, and the old mines made little profit. Specimens collected from Tienchuan were analyzed by C. H. Young, chemist, of the Geological Survey of China, with the following result:

	Percent		Percent
SiO_2	50.17	Alkalies	5.5
MgO	2.4	CaO	4.99
R_2O_3	29.18	Cu	.90

By microscopic study (12) I observed that the bornite is the only primary copper mineral. It is either sparsely disseminated in the basaltic lava or fills the vesicles in association with calcite, epidote, chlorite, and zeolites. Chalcocite has replaced bornite, either forming veinlets or occurring along its border fringe. Chalcocite has been in turn replaced by covellite, and a few grains of native copper have been recognized. The general sequence of principal minerals, beginning with the oldest, is anorthite, ilmenite, chlorite, quartz, epidote, zeolite, calcite, bornite, and chalcocite. The origin of this deposit, in my opinion, may be explained by the concentration of the copper mineral from the flow shortly after the lava effusion.

Yungching, Szechuan

Copper-bearing calcite veins occur at Chienchupa and other places in the Yungching district, southwestern Szechuan (12). The veins with well-defined walls and steep dip are confined to the Permian basaltic lava. Their thickness ranges from a few decimeters to more than 1.5 meters. The ore minerals are chalcopyrite, pyrite, sphalerite, and pyrargyrite, with a gangue of calcite and some quartz. I believe that the veins were also produced by the after-effects of igneous activity, filling up the fractures or cracks of the lava soon after its eruption.

Similar copper-bearing calcite veins in the Permian basaltic lava have been found near Lungman, southwest of Omeihsien, in southwestern Szechuan.

Northeastern Yunnan

Copper deposits in Permian basaltic lava are widely distributed in the eastern part of Yunnan. The ores are usually of low grade, but some valuable deposits have been formed by concentration by circulating waters.

Copper-bearing basaltic lava is widely distributed in this area, but only a few places are of economic importance. The following are some examples:

Tungchuan.—In the northern and northeastern parts of the Tungchuan district the Permian basic lava is widely distributed and is overlain by Permian sandstone and limestone. Native copper with some copper sulphides has been found along the contact of the basic lava and sandstone, especially in the cracks of the sandstone, as in Tsuili, Houyenchieh, and Sinfatung. At Tsuili, 13 kilometers north of Tungchuan, fairly large masses of native copper have been mined. Houyenchieh, 30 kilometers north of Tungchuan, was more productive in the years of Tungchih and Kuanghsu, of the Ching dynasty, but the mines are now abandoned. Sinfatung, where a lump of native copper 1 by 3 by 5 meters in size was found, is 20 kilometers northeast of Tungchuan.

T'angtang.—Copper sulphides in association with quartz form steeply dipping veins in the lava at T'angtang, Hsuanwai. The ore is said to run more than 10 percent of copper.

Weitoushan.—The deposit at Weitoushan, southwest of Kienshui (formerly Linan), produced about 60 tons of copper annually. Here three veins carry quartz with bornite and chalcopyrite in deeply weathered basaltic lava. The concentrate contains about 20 to 25 percent of copper.

Lunan.—Copper deposits have been found north and northwest of the city of Lunan, at Lunanyi, Maoshuitung, Lanching, and other places. They consist of carbonates of copper either in the basaltic lava or at its contact with the limestone.

A similar deposit has been found at Tungchangpo, Wannin, in western Kueichou, near the border of Yunnan. The copper tenor is generally less than 3 percent.

Sedimentary copper deposits

Chienchupa, Yungching, Szechuan

Copper ore is found near Chienchupa, a little more than 10 kilometers north of the city of Yungching, in southwestern Szechuan (12). (See figs. 105, 106.) No regular mining is done here, but the ore is collected by local farmers during spare time. The copper ore occurs in a Triassic bed immediately overlying the Permian

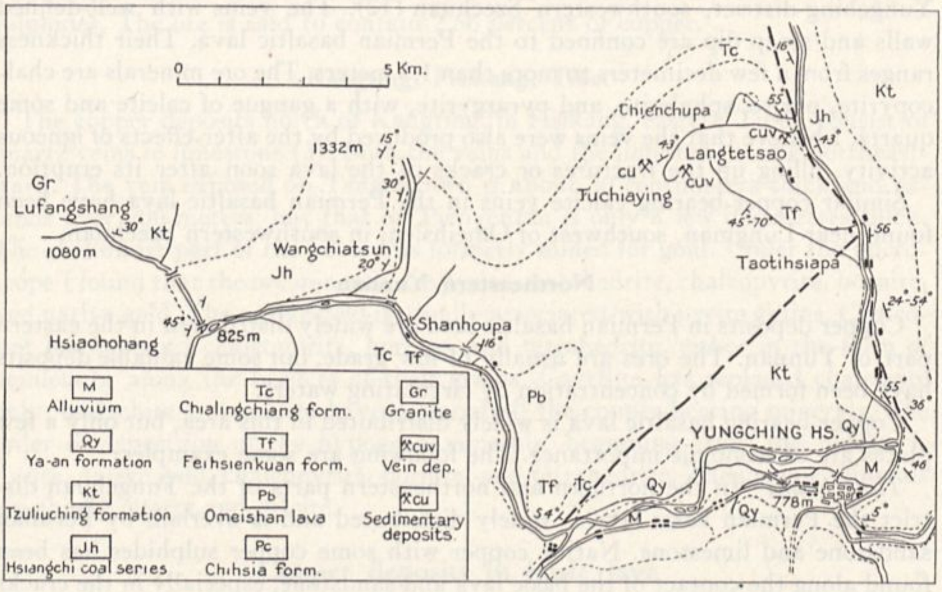


FIGURE 105.—Geologic sketch map of the area containing the copper deposits of Chienchupa, Szechuan, China. (After T'an and Lee.)

basaltic lava. The copper-bearing gravish-black sandy shale, usually 2 to 8 meters thick, is rich in charred wood (conifers), or fusain. The copper ores are replacements of fusain in nodular shape, 5 to 30 millimeters in diameter, or veinlets with carbonaceous material between them. The chief copper-bearing mineral in the nodules is bornite, which has replaced chalcopyrite with pyrite inclusions. The ore minerals chalcopyrite and pyrite occur usually within the cells of the wood, and their thickness ranges from that of a sheet of paper to 2 millimeters. Many of them show good cellular structure suggesting coniferous wood.

The field occurrence of the deposit indicates clearly that the cupriferous sediments were deposited in shallow water bordering an old land covered by the Permian basalt. Copper was originally contained in the basalt and was carried to the water in part as sulphate solution and in part as cupriferous detritus. This small amount of copper in the sediments was dissolved and later reprecipitated and concentrated chiefly by the reducing action of the fusain, a charred form of the wood derived most probably from forest fires, and was drifted along and deposited togetherwith the sediments. Bacterial action may have had some influence on the deposition, but clear evidence is not yet available. From this interpretation, it is evident that ore of this type represents simply reworked and redeposited copper from the zeolitic ore described in the preceding section.

The nodules of chalcopyrite or bornite, under microscopic investigation, show no concretionary structure but have distinct cellular structure, indicating replacement origin. The replacement of vegetable matter probably began at different points in a piece of wood and gradually extended outward in spherical form.

A similar occurrence of sedimentary copper ore in Triassic beds of the basaltic copper region has been found near Lungman, southwest of Omeihsien, in southwestern Szechuan.

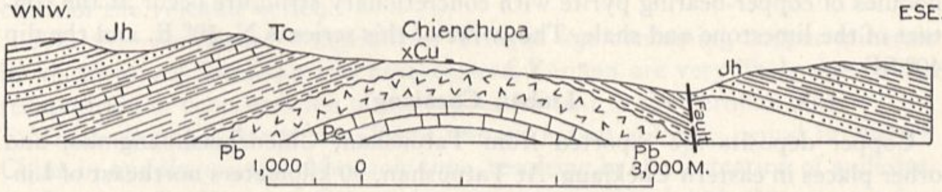


FIGURE 106.—Diagrammatic section through the Chienchupa copper deposits. (After C. Y. Lee.)

Eastern Yunnan

T'angtang.—In the eastern part of Yunnan the Permian basic lava is overlain by Triassic coal beds and reddish coarse sandstone of continental origin. Copper carbonates have been found in this sandstone. Geographically this formation is widely distributed, extending over an area from Wainin on the north to Loping on the south and from a point east of the Niulankiang River to a point west of Pingi. In this region copper ore is exposed and mined in several places. This cupriferous formation is especially thick near T'angtang, in Hsuanwai. The grade of the ore is about 4 percent. The Triassic coal beds, which generally constitute the copper-bearing formation, readily furnish the fuel for smelting the copper ore.

Tienpaoshan.—The Tienpaoshan copper deposit occurs near Pochen, a few kilometers northeast of Yuchi or Hsinhsingchow (formerly Hsiuna). There are three ore beds interstratified, with sandstone floor and shale roof, which are probably of Carboniferous age. Their thicknesses are 0.3, 0.5, and 0.6 meter. The ore is nodular and rich in copper carbonate.

Tungkung and Hsiku, Nanchang, Hupeh

The deposits at Tungkung and Hsiku are about 80 kilometers south of Nanchang, in northwestern Hupeh (14). The middle limestone of the Patung series, of Triassic age, has some columnar chalcocite and malachite deposits at the base. The deposits were prospected but not developed by the King-hua Mining Co. H. M. Meng believed that the ores were formed through the concentration by meteoric water of the copper contained in the limestone.

Dschurger, Sinkiang

Copper ore has been found at Dschurger, near Paicheng, and in the Aksu district. Ore occurs in the shale interbedded with sandstone. The copper-bearing shale is 4 to 5 meters thick, and hundreds of shafts were sunk for mining. The ore minerals are malachite and azurite scattered in the shale.

Deposits of uncertain origin

Below are briefly mentioned a few deposits which may have some economic significance but of which our geologic knowledge is too poor to justify any attempt at classification of their origin.

Chouchiatsun, Wuwei, Anhui

The deposit at Chouchiatsun, Anhui, is 15 kilometers south of Wuwei. Here four thin layers of shale with pyrite are interbedded with black limestone. Flat nodules of copper-bearing pyrite with concretionary structure occur at the contact of the limestone and shale. The strike of this series is N. 50° E. and the dip 40° SE.

Linhai, Chekiang

Copper deposits are reported from Tatoushan, Chienchiashuangmao, and other places in eastern Chekiang. At Tatoushan, 30 kilometers northeast of Linhai, the deposits occur west of the hill, about 50 meters above the adjacent valley. The ore minerals are chalcopyrite, pyrite, bornite, chalcocite, galena, and malachite in association with calcite veins in the cracks of rhyolite tuff. The thickness of the vein is only a few centimeters. At Chienchia the ore body is only 8 centimeters thick at the surface, but it widens to 1 meter at a depth of more than 3 meters. The ore at the surface is chiefly malachite, but it gradually changes to galena and chalcopyrite in depth. The vein is nearly vertical and strikes N. 75°W.

Hsipushan, Kunghsien, Kiangsi

Copper ore has been found at Hsipushan, near Lungshia, Kunghsien, Kiangsi. In this region granite is the predominant rock. The ore has been reported to carry 3 to 4 percent of copper.

Tungchiehchang, Suinin, Hunan

The deposit at Tungchiehchang (6) is about 65 kilometers southwest of Suinin, Hunan. In 1913–15 the ore was mined by the Fu-li Mining Co. The chief ore minerals are chalcopyrite and oxidized copper-bearing minerals.

Hochangshan, Minhou, Fukien

The deposit at Hochangshan is 48 kilometers southwest of Minhou, the capital of Fukien. The ore vein, about 27 meters thick and 320 meters long, occurs in granite. The chief ore minerals are chalcopyrite and pyrite in a quartz gangue.

Chunan, Shensi

In the copper deposit north of Chunan, Shensi, near the border of Hupeh, the ore mineral so far known is chiefly native copper.

Age of copper deposits in China

Because of the wide distribution of the copper deposits of China it is evidently difficult to give a review with any claim of completeness. The effort has been made above, however, to describe briefly deposits of the principal types, including almost all formations of possible economic value. A summary of the ore deposition in the order of geologic periods is given below.

Pre-Cambrian.—The hydrothermal mineralization of the quartzite, schists, and gneissic rocks in southwestern Shansi and northwestern Honan probably occurred in pre-Cambrian time. The deposits of this type are usually of relatively wide extent, although their average copper percentage is generally low.

Permian.—The Permian lava, generally called "basalt" but sometimes also "andesite," is widespread in southwestern Szechuan, northeastern Yunnan, and a part of Kueichou. Copper-bearing minerals occur in the lava, disseminated in veinlets, or as amygdules. The deposits were formed probably through the after effect of the volcanic action.

Triassic.—Sedimentary deposits of Triassic age containing copper minerals in southwestern Szechuan and northeastern Yunnan are very likely due to the redeposition or concentration of the copper content in the Permian lava.

Middle or upper Mesozoic.—There was an active volcanic period in eastern China in middle or upper Mesozoic time, resulting in the formation of andesite, trachyte, or rhyolite lava. Copper deposits are associated with the volcanic formation in Hopeh, Chekiang, and Fukien. Most of these deposits are very small.

Late Mesozoic or early Tertiary.—Many copper deposits in Hupeh, Hunan, Kiangsi, Kiangsu, Honan, and Kirin are believed to be in close genetic relation with a granitic, syenitic, or dioritic intrusion. The age of this intrusion has been repeatedly discussed (15) and generally accepted as late Mesozoic or early Tertiary. The igneous action resulted in the formation of numerous iron, copper, lead, and zinc deposits. The effect of contact metamorphism is especially clear in the copper deposits of Yangsin and Tayeh, in Hupeh, where the close association between copper and iron ores of similar origin may be also observed. The ores of such deposits are usually of higher grade, though their dimensions are not certain. Other deposits may be also related to such intrusion but show less evidence of it.

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Copper deposits of India

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Introduction

Copper was formerly smelted in considerable quantities in small native furnaces in southern India, in Chota Nagpur, in Rajputana, and along the outer Himalaya, in which a persistent belt of killaslike rock is known to be copper-bearing in numerous places, as in Kulu, Garhwal, Nepal, Sikkim, and Bhutan. Copper-ore deposits have also been found in places where there were no old workings. In all these places the rocks in which the lodes occur are of pre-Cambrian age (usually Archean). European enterprise has been directed to the investigation of some of these deposits, particularly at Baraganda, in the Hazaribagh district, Bihar and Orissa; at several localities in Singhbhum, in the same province; at Sleemanabad, in the Central Provinces; and in Sikkim. In Burma copper ores have been discovered at several localities, but the only deposit of economic importance is that of the Bawdwin lead-silver-zinc mine, in the Northern Shan States, where copper ores are also mined. Space will permit only an account of the occurrences of Singhbhum, Sikkim, and Bawdwin.

Singhbhum

In the Singhbhum district of Bihar and Orissa, a copper-bearing belt of Dharwar (Archean) schists, marked out by old workings, persists for some 80 miles from Duarparam (22°45′ N., 85°38′ E.), on the Bamani River in the Kera estate, in an easterly direction through the Kharsawan and Seraikela States into Dhalbhum, where the strike of the belt curves to the southeast through the Rajdoha and Matigara properties, formerly belonging to the Cape Copper Co., to Bhairagora (22°16′ N., 86°46′ E.), at the extreme southeast end. This belt is crudely parallel to the boundary between the Dharwar beds and the underlying but intrusive granite of central Singhbhum. The copper ores occur as rather indefinite lodes of chalcopyrite with pyrite interbedded with the Dharwar phyllites and schists. Some of the ore is concentrated in fairly well defined bands, but much of it occurs in the form of grains so sparsely disseminated through a considerable thickness of schists as to be unworkable. Where it is concentrated into definite lodes, as at Matigara or Mosaboni, the ore may be of high grade.

These copper ores have been the subject of exploitation by European methods by various companies at intervals since 1857, always with disastrous results, until the present century, at the beginning of which private enterprise had come to a standstill. The Geological Survey of India, consequently, during the years 1906–8 carried out a series of diamond-drilling operations on the belt. The favorable indications obtained redirected private enterprise to this district, and the Cape

Copper Co., Ltd., took over the Rajdoha Mining Co.'s rights at Matigara and by 1918 had proved reserves in the Rakha Hills mine amounting to 407,000 short tons of an average assay value of 3.8 percent of copper. A concentration plant, blast furnace, sintering and converting plants were erected, and during the 5-year period 1919–23 the total production of copper ore and metal was 130,797 and 3,550 long tons respectively, valued at Rs. 18,08,141 ($659,961) and Rs. 41,58,154 ($1,517,726). In 1923, however, mining operations ceased, and the company's property was placed in the hands of receivers.

In 1920 the Cordoba Copper Co. began investigation of the Mosaboni area, farther southeast. This company was reconstructed in 1924 as the Indian Copper Corporation, which acquired also other copper properties in Singhbhum. Work was concentrated upon the Mosaboni area, however, and milling and smelting plants were erected at Moubhandar, near Ghatsila. The first production of copper was 1,635 long tons of refined copper ingots and slags in 1929, which increased to 4,443 long tons in 1932, of which 3,441 long tons of copper was converted into 5,444 long tons of yellow-metal sheet. The ore reserves at the end of 1932 were 700,466 short tons of ore carrying 3.053 percent of copper.

The characteristic ore mineral of Singhbhum is chalcopyrite, which, both at Rakha and at Mosaboni, occurs as a persistent band of varying thickness up to 2 feet and giving a tenor of 10 to 25 percent of copper. On both sides of this band occur schists containing disseminated chalcopyrite, and the two together yield ore averaging 3 to 4 percent as worked at the Rakha and Mosaboni mines. The following table giving results of diamond drilling on the Singhbhum copper lodes, as carried out by the Geological Survey of India many years ago, indicates the great variability both in thickness and quality of the copper lodes at Singhbhum.

Results of diamond-drill boring on the Singhbhum copper lodes

No.	Locality	Total depth of hole	Depth of lode or cupriferous zone: Top	Depth of lode or cupriferous zone: Bottom	Actual thickness of lode assayed	Percent of copper
		Feet	*Ft. in.*	*Ft. in.*	*Ft. in.*	
1	Kodomdiha	....	392	404	8	5.10
2	...do.	1,093		1,069	1	1.82
3	Galudih (Regadih)	430	131	294	1 1	.61
4	Landup (Nadup)	465	197	198	1 2	3.33
5	Matigara	837	693	697	3 2	2.00
			697	701 8	3 8	1.29
			733 5	736 1	2 1	1.01
			736 1	736 5	3	12.81
			736 5	739	2	.42
6	Laukisra	392	150	168	16 10	2.65
			169	171	1 10	2.13
			179	184	4 8	1.37

Sikkim

In Sikkim, a small Indian State in the Himalaya north of Darjeeling, numerous metalliferous lodes have been discovered containing ores of copper, lead, and zinc. The two most important of these are cupriferous lodes at Bhotang (27°11′ N., 88°34′ E.) and Dikchu (27°33′ N., 88°38′ E.), upon both of which prospecting was done from about 1908 to 1911 by Burn & Co., of Calcutta. At Bhotang, 44 miles from Siliguri on the road to Gangtok, some old workings were examined and two parallel lodes of pyrrhotite were opened up and found to contain various quantities of zinc blende, galena, and chalcopyrite. At Dikchu, about 7 miles north of Gangtok, a more clearly defined copper lode crops out for a length of 200 feet, with an average outcrop width of 3 feet and a content of 6.14 percent of copper. An adit in the lode at greater depth revealed, over a length of 80 feet, an average width of 40 inches with 6.8 percent of copper. Neither of these two deposits has been further developed, owing partly to inaccessibility of the areas and lack of adequate communications. Both deposits were examined by me in 1911. They are replacement deposits interbedded with the associated rocks; but whereas the Bhotang deposit is in a comparatively unmetamorphosed form of the Daling series (Archean), the Dikchu deposit occurs in a belt of highly crystalline mica schists with associated gneisses, forming a boundary zone between the Daling series and the Sikkim gneiss. In both places the copper ore mineral is chalcopyrite and the chief associated sulphide is pyrrhotite, but, especially at Bhotang, galena and blende are also of somewhat common occurrence.

Comparison of Sikkim and Singhbhum

The origin and mode of occurrence of the Sikkim ores appear to be similar to those of the Singhbhum copper lodes. In each area the bodies of copper ore have been formed by the metasomatic replacement of the associated rocks, and in each area also the copper-bearing formations are close to large masses of granitic rocks, to which may be ascribed the derivation of the copper-bearing solutions. In Singhbhum, however, there are also numerous basic (epidioritic) dikes associated with both the granites and the metamorphic rocks (schists, quartzites, etc.), and, as an alternative hypothesis for the derivation of the copper-bearing solutions, they may have been closely connected with these dikes.

Although the deposits of Sikkim are thought to be similar in mode of origin to those of Singhbhum, they differ remarkably in the diversity of their mineral contents, which in many places include chalcopyrite, pyrite, pyrrhotite, blende, and galena. In Singhbhum, on the other hand, the copper lodes show, as a rule, only two sulphide minerals, chalcopyrite and pyrite, with traces of chalcocite at higher levels, probably representing a zone of enrichment. In both Sikkim and Singhbhum azurite, malachite, chrysocolla, and chalcanthite are found in the oxidized zones of the lodes, but in Sikkim, where the slopes are very steep and denudation under the influence of a moist climate and heavy rainfall is very rapid, the oxidized zones are much less prominent than in Singhbhum. In Sikkim the sulphide minerals may crop out at the surface in the fresh condition, but this practically nowhere occurs in Singhbhum, where the existence of copper deposits might be doubted were it not for the presence of numerous ancient outcrop workings stained with green and blue oxidized copper minerals.

Bawdwin

In Burma copper ore is found in portions of the Bawdwin silver-lead-zinc mine, in the Northern Shan States. In the neighborhood of Bawdwin (23°7′ N., 97°20′ E.) the Bawdwin volcanic series (probably pre-Cambrian or early Cambrian) of rhyolitic tuffs, flows, and breccias, with coarse feldspathic grits, has been intensely crushed and dislocated by overthrust faulting. The main ore channel is in this faulted zone. Ascending ore-bearing solutions have metasomatically replaced the tuffs, with the introduction of sulphides along what is known as the Bawdwin fault. This fault has been traced for a length of about 7,000 feet, and work along a part of this distance has disclosed the presence of two main ore bodies, named the "Chinaman" and "Shan" lodes. The ores are mainly an intimate mixture of galena and blende, locally with chalcopyrite also. Pure unmixed chalcopyrite is also found in parallel bands alongside the mixed bands. The extraordinary size and richness of these lodes is well known in the mining world. The ore reserves on June 30, 1932, were estimated by the Burma Corporation, Ltd., at 4,126,179 tons, assaying 19.7 ounces of silver to the ton, 25.4 percent of lead, 15.6 percent of zinc, and 0.68 percent of copper. Included in the somewhat similar figures for the preceding year were 111,000 tons of copper ore, with an average composition of 5 percent of copper, 14 percent of lead, 6 percent of zinc, and 16 ounces of silver to the ton of lead. The ores are smelted at Namtu, near Bawdwin, and the products for the year ending June 30, 1932, included refined lead, 70,560 tons; refined silver, 5,842,789 ounces; zinc concentrates, 46,905 tons; copper matte, 10,349 tons; nickel-speiss, 3,002 tons; and antimonial lead, 812 tons. The copper matte produced during the calendar year 1932 amounted to 9,729 tons containing 83.73 ounces of silver to the ton, 26.36 percent of lead, and 44.32 percent of copper. The nickel-speiss production for the same year was 3,579½ tons, containing 32.99 ounces of silver to the ton, 12.87 percent of copper, and 25.98 percent of nickel. Both the copper matte and the nickel-speiss are exported for further treatment.

Production

Copper ore, copper, brass, copper matte, and nickel-speiss produced in India (including Burma), 1909–32, in long tons

Year	Singhbhum district, Bihar and Orissa			Burma	
	Copper ore	Refined copper	Yellow metal (brass)	Copper matte	Nickel-speiss
1909	7				
1910	864			[a]290	
1911	2,079			[a]159	
1912	8,984			[a]624	
1913	3,639			[a]150	
1914	4,400			[a]924	
1915	8,010			[a]875	
1916	4,135				
1917	20,108				
1918	3,619				
1919	32,756	980		[a]2	
1920	28,167	512			
1921	32,560	833			
1922	30,764	1,037			
1923	6,550	187			
1924				[a]2,935	
1925	26,319			8,029	
1926	9,504			11,441	
1927	5,000			11,872	1,032
1928	18,055			10,978	2,933
1929	76,831	1,635		11,303	3,065
1930	123,749	2,974	712	17,146	3,150
1931	153,636	4,069	3,637	13,437	2,911
1932	175,010	4,443	5,440	[b]9,729	[c]3,579

[a] Copper ore.
[b] Composition of copper matte in 1932: Ag, 83.73 ounces to the ton; Pb, 26.36 percent; Cu, 44.32 percent.
[c] Composition of nickel-speiss in 1932: Ag, 32.99 ounces to the ton; Cu, 12.87 percent; Ni, 25.98 percent.

For information concerning the values of this production the reader is referred to the annual and quinquennial reviews of mineral production of India, appearing in the Records of the Geological Survey of India.

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Copper resources of Japan

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Introduction

The history of copper in Japan is very old. There is a statement in our chronicle that the province of Musashi presented the metal copper to the Imperial Court in 708 A.D. From that time until 1870 the production increased steadily except for a few interruptions, but no statistics are available for this period. A marked increase in production took place about 1870, owing to the opening of several new mines and the introduction of foreign mining and metallurgical processes. Production continued to increase until the World War, which brought about a second great change. In 1917 the total production reached its maximum of 108,038,369 kilograms, valued at 118,692,244 yen. From that date it gradually decreased until 1922, when it amounted to only 54,126,274 kilograms. In 1923 there was a slight recovery in production, since which it has in general continued to increase to the present time, although not without fluctuations. The output in recent years according to statistics compiled by the Bureau of Mines was as follows:

	Kilograms	Yen		Kilograms	Yen
1877	3,942,446	1,432,372	1921	54,957,490	33,046,934
1887	11,063,768	2,419,499	1922	54,126,274	37,427,163
1897	20,389,330	7,834,940	1923	59,345,713	44,345,682
1907	32,261,399	32,467,871	1924	63,056,092	48,541,691
1912	62,422,499	40,252,061	1925	66,486,999	53,467,966
1913	66,501,245	42,012,126	1926	67,365,449	50,766,711
1914	70,463,449	39,057,387	1927	66,571,249	47,888,858
1915	75,415,639	53,731,798	1928	68,232,865	55,271,862
1916	100,635,521	109,812,610	1929	75,469,049	69,399,811
1917	108,038,369	118,692,244	1930	79,032,844	50,231,252
1918	90,341,293	90,390,232	1931	75,848,181	33,627,912
1919	78,443,317	67,581,475	1932	71,876,557	36,120,840
1920	67,792,429	47,577,402			

The production is quite enough to supply domestic demands, and about 5 to 10 percent of it was exported every year.

Deposits

Deposits of copper are widely distributed in Japan, more than 110 mines having been worked in 1932. (See pl. 39.) The ores of copper are mostly chalcopyrite, rarely tetrahedrite and enargite; secondary minerals include chalcocite, bornite, malachite, chrysocolla, etc. According to their mode of occurrence they can be classified into contact-metasomatic deposits, replacement deposits, and fissure veins.

Contact-metasomatic deposits

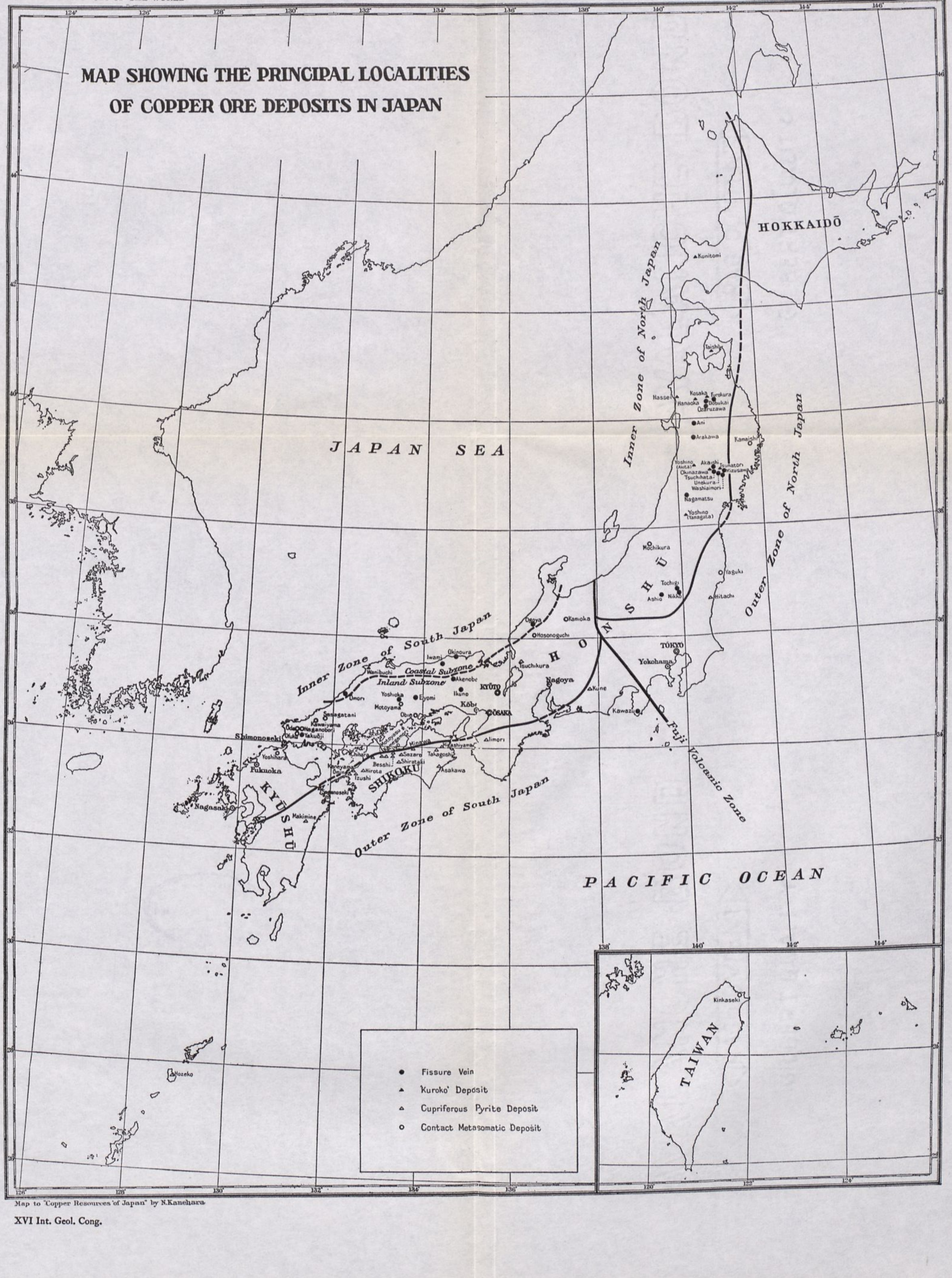
The contact-metasomatic deposits are characterized by the presence of gangue minerals such as pyroxene, garnet, epidote, and wollastonite. They commonly occur in the Paleozoic rocks, being especially numerous at the contact of limestone with granite or allied rocks. The ore consists mostly of chalcopyrite mixed with sulphide minerals such as pyrite, pyrrhotite, arsenopyrite, galena, and zinc blende, and rarely with oxide ores such as hematite and magnetite. It commonly contains small quantities of gold and silver.

Although copper deposits of this type are widely distributed in Japan, only a few of them have hitherto been developed. Three were being worked in 1932, and less than 1 percent of the copper production of that year was derived from these mines. The following is a brief description of the principal mines working the contact-metasomatic deposits.

The Yaguki mine is on the Pacific side of the middle part of Honshu, about 400 kilometers northeast of Tokyo. The rocks of the district consist of Paleozoic slate, hornstone, and sandstone accompanied by limestone. Granodiorite and serpentine are found as dikes or stocks traversing the Paleozoic formation, which has been altered into phyllitic or schistose rocks at the contact. The deposits are found chiefly in limestone, though a few occur at the contact of Paleozoic sedimentary rocks and granodiorite and are genetically connected with the granodiorite. The size of the largest ore mass is estimated at about 1,000 meters in length (along the strike), 250 meters in breadth (along the dip), and 20 meters in thickness. The ore consists of chalcopyrite, pyrite, pyrrhotite, arsenopyrite, and magnetite, together with some zinc blende and galena. The gangue minerals are mostly garnet, hedenbergite, and babingtonite, though some epidote and ilvaite are also present. The average grade of the ore is about 1.5 percent of copper. The deposit was discovered in 1393 A.D. The production of copper in 1924 was 125,763 kilograms; in 1925, 206,100 kilograms; in 1926, 230,923 kilograms.

The deposits of the Mochikura, Ofuku, Naganobori, Ōda, and Yoshihara mines belong to the same type, genetically connected with granite or quartz diorite.

The Sasagatani mine is at the western extremity of Honshu, about 95 kilometers northeast of Shimonoseki. Of the geologic formations near the mine, the most prominent is the Paleozoic, consisting of sandstone, slate, quartzite, and limestone, which strike east and dip about 60° N. Traversing these Paleozoic rocks are minor dikes of quartz porphyry and pyroxene andesite. The deposit occurs in both limestone and sandstone, and also at or near their contact with


MAP SHOWING THE PRINCIPAL LOCALITIES
OF COPPER ORE DEPOSITS IN JAPAN
JAPAN SEA
PACIFIC OCEAN
HOKKAIDŌ
HONSHŪ
SHIKOKU
KYŪSHŪ
TAIWAN
Inner Zone of North Japan
Outer Zone of North Japan
Inner Zone of South Japan
Outer Zone of South Japan
Coastal Subzone
Inland Subzone
Fuji Volcanic Zone
Kunitomi
Taishu
Kosaka
Furokura
Hanaoka
Ani
Arakawa
Kamaishi
Nagamatsu
Mochikura
Yaguki
Tochigi
Ashio
Nikko
Hitachi
Kamioka
Hosonoguchi
TŌKYŌ
Yokohama
Kune
Kawazu
Nagoya
KYŌTO
ŌSAKA
Kōbe
Ikuno
Akenobe
Okinoura
Iwami
Omori
Yoshioka
Motoyama
Ebumi
Iimori
Besshi
Shirataki
Sazare
Takagoshi
Asakawa
Minawa
Shimonoseki
Yoshihara
Fukuoka
Nagasaki
Makimine
Kinkaseki
Hozeko
Fissure Vein
'Kuroko' Deposit
Cupriferous Pyrite Deposit
Contact Metasomatic Deposit

dikes of lithoidal quartz porphyry, which is considered to be the ore bringer. In limestone the deposit forms an elongated mass; in sandstone it is veinlike. The largest ore mass is that of Takachiogiri, which is 600 meters long, more than 220 meters wide, and 100 meters thick. Chalcopyrite, arsenopyrite, and zinc blende occur in connection with bornite, pyrrhotite, and galena. Hedenbergite, wollastonite, and garnet occur as gangue minerals. The ore contains 2.5 to 6 percent of copper. According to tradition, the deposit was discovered about 650 years ago. The deposit is the largest of the contact-metasomatic type now being worked. The production of copper in the 5 years 1927–31 was as follows:

	Kilograms		Kilograms
1927	238,783	1930	214,899
1928	255,530	1931	105,497
1929	350,935		

The contact-metasomatic deposits of Hosonoguchi, Motoyama, and Kawaiyama, are also genetically connected with the intrusion of quartz porphyry or porphyrite.

The output from the contact-metasomatic deposits during the 5 years 1927–31, except that of the Sasagatani mine, was as follows:

Mine	1927	1928	1929	1930	1931	Grade of ore (percent)	Geology
Kamaishi ore. (tons)	25	....	407	2,446	....	Cu 5.13, Fe 69.0	Paleozoic, granite.
Kamioka..copper (kilograms)	12,840	12,273	59,985	99,745	167,164	Cu 0.9, Pb 55.3, Au 0.0005, Ag 0.0318, Bi 0.13, As 0.069.	Gneiss, Paleozoic, granite.
Ofuku....ore (tons)	1,900	1,418	1,805	1,123	200	Cu 3.08, Ag 0.014.	Paleozoic, quartz diorite.
Motoyama....do	....	....	620	250	....	Cu 3.19, S 14.0, Fe 24.0	Paleozoic, porphyrite.

Replacement deposits

The replacement deposits may be divided into two kinds. One is lenticular or bedlike in form and consists of cupriferous pyrite; the other is the so-called "kurokō" (black ore), an intimate mixture of galena, zinc blende, and barite. In 1931 deposits of the former kind were worked in 29 mines and deposits of the latter kind in 9 mines, and more than 50 percent of the copper produced in Japan was obtained from these mines.

Lenticular or bedlike deposits

The lenticular or bedlike deposits occur mostly in the highly metamorphosed crystalline schists, rarely in the Paleozoic or Mesozoic, in close relation with green schists or amphibolites derived from basic igneous rocks. The crystalline schists comprise sericite gneiss, sericite schist, piedmontite schist, chlorite schist, and graphite schist, in many places accompanied by amphibolite, serpentine, and other metamorphic basic igneous rocks. It is noteworthy that no granitic rock is found in the environs of the mining district, except at a few mines in the Paleozoic formation, and from this it may be inferred that deposits of this type are genetically connected with basic igneous rocks. The ore body is generally conformable to the bedding of the country rock, having a lenticular shape due to elongation along either strike or dip, and swelling and pinching in both directions. In some deposits, however, especially those occurring in the terrane of highly metamorphosed crystalline schists, the ore body is intricately folded and bent, together with the wall rocks. The ore is commonly a compact crystalline massive pyrite and is in many places associated with chalcopyrite, pyrrhotite, hematite, or magnetite, besides small quantities of gold and silver. The copper content of the ore is extremely variable but usually about 2 percent or more, so that the ore is generally mined for copper, or, if the copper tenor is very low, for sulphur.

The chief replacement deposits, such as those of Hitachi, Kune, Iimori, Asakawa, Higashiyama, Takagoshi, Minawa, Sazare, Besshi, Chihara, Izushi, Kanayama, and Makimine, belong to this type and are still being worked. Those of Besshi and Hitachi are especially noteworthy.

The Besshi mine, which is one of the largest of this kind, is in the middle part of Shikoku. The region is composed chiefly of alternations of quartz schist, quartz-sericite schist, chlorite schist, and graphite schist, pierced by serpentine and amphibolite. The deposit measures more than 1,600 meters along the strike and more than 1,200 meters along the dip and is in general 6 to 10 meters thick. It consists of massive cupriferous pyrite and fahlbandlike banded ore cut by a chalcopyrite vein and is enclosed in chlorite schists and graphite schists. The massive cupriferous pyritic ore, which is most common, consists of minute grains of pyrite firmly cemented by chalcopyrite. This ore, which forms tabular masses along both walls, attains a maximum thickness of 4.5 meters and contains about 3 percent of copper and about 2 percent of silica. A banded ore is intercalated between the compact pyritic masses found along the hanging and foot walls and ranges in thickness from 0.5 to 6 meters. It consists of chlorite schist and quartz schist interstratified with thin layers of the aggregate of pyrite and chalcopyrite and contains about 3 percent of copper and about 30 percent of silica. A high-grade chalcopyrite ore occurs in the form of a vein from 4 to 6 centimeters in width, which cuts the ore and contains about 20 percent of copper and about 3 percent of silica. It is composed of almost pure chalcopyrite, although a massive aggregate of magnetite is found here and there along its border. This high-grade ore indicates a later deposition of chalcopyrite along a fissure formed in the highly mineralized green schist.

The ore deposit was discovered in 1690 A.D. Mining and smelting operations were begun during the next year and continued to the present time. The production of copper to the end of 1932 was as follows:

	Kilograms		Kilograms
1690–1927	211,269,251	1930	16,586,395
1928	13,244,237	1931	13,226,957
1929	15,418,712	1932	10,598,799

The Hitachi mine represents another interesting type of the cupriferous pyritic deposits of Japan. It is about 150 kilometers northeast of Tokyo, on the coastal Joban line of the Government Railway. The rocks nearby are Paleozoic amphibolite, biotite schist, phyllite, clay slate, limestone, etc., and intrusive granodiorite and diorite. The rocks near the granodiorite are highly metamorphosed, carrying contact minerals such as andalusite and cordierite. The deposits are found chiefly either in amphibole schist or in chlorite schist, rarely in sericite schist. They are arranged along the planes of schistosity of these rocks and are considered to have been formed by hydrothermal metasomatism that followed the intrusion of granodiorite and diorite. There are more than 100 ore bodies in all, arranged parallel to one another in an area measuring 1,500 by 500 meters. They are generally of a flattened lenticular form, though some are irregularly massive and cut the bedding planes of the country rock. The principal deposits are Sasame, Chusei, Kammine, Honko, Akazawa, Takasuzu, and Irishiken. The Sasame deposit is about 150 meters long and 2 meters wide; the Chusei, 400 meters long and 6 meters wide; the Kammine, 300 meters long and 7 meters wide; the Honko, 450 meters long and 4 meters wide; the Akazawa, 120 meters long and 14 meters wide; the Takasuzu, 150 meters long and 12 meters wide; and the Irishiken, 150 meters long and 0.6 meter wide. The principal ore minerals are pyrite, pyrrhotite, chalcopyrite, and rarely zinc blende, with some chlorite, quartz, and barite as gangue minerals. As the ore contains from 2 to 4 percent of copper it is used mainly for copper smelting.

The deposit was discovered about 400 years ago and was then considered small. In 1912 it came under the control of the Kuhara Mining Co., and since then many rich deposits have been struck, so that the mine has become an important copper producer of Japan. The production of copper from 1912 to 1932 was as follows:

	Kilograms		Kilograms
1912–27	171,149,719	1930	8,546,054
1928	6,934,616	1931	8,361,230
1929	7,755,338	1932	7,685,191

The output of the other principal mines in cupriferous pyrite deposits during the 5 years 1928–32 was as follows:

Production of certain mines in cupriferous pyrite deposits in Japan, 1928–32

Mine	1928	1929	1930	1931	1932	Grade of ore (percent)	Geology
Kune.........ore (tons)..	37,569	37,700	30,707	19,636	19,853	Cu 4.0, S 40........	Schist.
Tsuchihata.........do....	2,850	2,524	2,124	8,936	9,513	Cu 4.5, S 42........	Paleozoic.
Iimori.........do....	30,552	23,152	28,747	22,401	29,473	Cu 2.6, S 40........	Schist.
Asakawa.........do....	2,285	4,087	3,780	2,720	5,155	Cu 5.9, S 37........	Mesozoic.
Higashiyama.........do....	2,322	3,334	4,235	2,650.	2,327	Cu 3.79, S 42........	Schist.
Takagoshi.........do....	20,465	32,972	25,660	16,124	17,087	Cu 4.62, S 40........	Do.
Minawa.........do....	10,683	12,956	11,754	9,800	8,273	Cu 2.38, S 44........	Do.
Chihara.........do....	2,396	2,224	1,961	1,876	2,444	Cu 3.7, S 40........	Do.
Kamegamori.........do....	....	....	2,597	2,272	....	Cu 6.0, S 42........	Do.
Motoyasu.........do....	....	4,031	4,078	1,506	646	Cu 4.0, S 40........	Do.
Iyo.........do....	5,729	8,012	6,877	7,631	9,104	Cu 3.0, S 42........	Do.
Sazare.........do....	7,199	10,000	8,113	5,858	5,408	Cu 1.46, S 44........	Do.
Hirota.........do....	17,665	11,453	5,678	....	....	Cu 2.08, S 48........	Do.
Kanayama.........do....	2,296	440	1,815	1,146	9,991	Cu 9.0, S 36........	Do.
Izushi.........do....	....	5,713	9,165	11,448		Cu 2.85........	Do.
Oomori.........do....	4,753	5,504	2,009	....	....	Cu 3.1, S 38........	Do.
Shirataki.........do....	30,425	34,403	38,678	41,216	42,009	Cu 4.0, S 45........	Do.
Saganoseki.....copper (kilograms)..	8,054,167	10,940,222	13,596,931	10,741,957	10,021,089	Cu 1.5, S 36........	Do.
Makimine.........do....	1,008,715	1,208,607	1,366,767	1,255,937	1,375,922	Cu 4.02........	Paleozoic.
Hozako.........ore (tons)..	2,161	2,361	3,031	2,669	2,063	Cu 4.0, S 37.5, Ag 0.0005...	Do.

"Kurokō" (black ore) deposits

The replacement deposits of the second group are found in tuffs or shales and also at or near the contact of these rocks with liparites or andesites. They are irregular in form and range from several meters to many hundred meters in length. They consist of ores of three different kinds—"kurokō," or black ore; "ōkō," or yellow ore; and "keikō," or siliceous ore. The "kurokō" is an intimate mixture of galena, zinc blende, and barite, usually accompanied by chalcopyrite and pyrite and containing variable quantities of gold and silver. The "ōkō" is a crystalline massive pyrite associated with a small amount of chalcopyrite. The "keikō" is a silicified liparite or tuff with a variable quantity of pyrite, together with some sulphide ore minerals forming "kurokō." These ores are usually associated in a complicated manner and form irregular masses.

The proportion of the above-mentioned ores as well as of the component minerals varies widely in different mines and even in different parts of the same mine. Some of the ores with a larger amount of zinc blende have been utilized as a source of zinc; others with a greater quantity of galena rich in silver have been worked for silver. Some are so rich in pyrite that they have been utilized for the production of sulphur. In general, however, these ores contain about 2 percent of copper, so that they are mostly mined for this metal. The boundary between the ore body and the country rock is either sharp or indistinct. The deposits are generally believed to be of metasomatic origin.

The Kosaka mine, which has the largest deposit of this kind, lies near the north end of Honshu, the main island of Japan. The rocks of the district surrounding the mine comprise liparite, dacite, andesite, propylite, and Tertiary sedimentary rocks. The liparite covers the widest area and is most intimately related to the ore deposit. So far as I am aware, the dacite, andesite, and propylite are later than the deposit. The Tertiary is represented by tuff, brecciated tuff, tuffaceous shale, and shale, of which the tuffs serve as the country rock of the deposit.

The main body of the deposit resembles in shape a Japanese turnip tapering sharply at the bottom. It has a longer diameter of about 750 meters. It is coated with a thick clayey substance on all sides except the southwest, where it is directly in contact with the sulphidized liparite. The three kinds of ore already described are present. The "keikō" is developed either at the margin or in the lower part of the ore body; in the upper part it encloses "ōkō," which in turn contains "kurokō." Much of the "keikō" is broken up into pieces which are cemented by "ōkō," indicating that the "ōkō" is younger than the "keikō." This age relation also reveals the later mineralization of "kurokō."

The deposit was discovered in 1861 A.D. and has been worked until the present time without interruption. The production of copper in 1912–32 was as follows:

	Kilograms		Kilograms
1912–27	139,163,722	1930	9,937,444
1928	8,947,900	1931	9,608,049
1929	9,197,986	1932	9,407,152

The copper production of the principal other mines belonging to the "kurokō" type during the 5 years 1928–32 is given on page 694.

Mine	1928	1929	1930
Kunitomi....copper (kilograms)..	410,770	508,339	453,581
Taisho.....................do....	240,500	711,000	613,321
Okinazawa..........ore (tons)..	2,320	804	1,606
Tsunatori..................do....	1,781	2,994	2,584
Hassei.......copper (kilograms)..	1,148,924	1,645,688	2,242,249
Hanaoka..............ore (tons)..	179,697	189,608	192,104
Yoshino (Akita)..........do....	11,353	13,460	19,004
Yoshino (Yamagata).......do....	1,902	3,493	3,202
Wanibuchi..............do....	1,469	1,230	1,221

Mine	1931	1932	Grade of ore (percent)
Kunitomi....copper (kilograms)..	29,129	....	Cu 3.5, Au 0.01.
Taisho.....................do....	434,000	....	Cu 3.0.
Okinazawa..........ore (tons)..	979	2,015	Cu 10.07.
Tsunatori..................do....	2,617	3,861	Cu 4.25, Au 0.0022, Ag 0.0035.
Hassei.......copper (kilograms)..	2,049,191	2,107,130	
Hanaoka..............ore (tons)..	199,324	208,204	Cu 4.63, Au 0.0008, Ag 0.005.
Yoshino (Akita)..........do....	18,319	23,810	Cu 4.63, S 43.0.
Yoshino (Yamagata).......do....	....	....	Cu 1.65, Zn 7.3, Au 0.00007, Ag 0.0063.
Wanibuchi..............do....	....	....	Cu 1.84, Zn 20.9, Ag 0.0189.

Fissure veins

A large number of productive mines belong to the fissure-vein type, more than 70 being worked at present. The ore is usually chalcopyrite with some pyrite or pyrrhotite. Bornite and chalcocite are mostly found in the oxidized zone of the deposit. Quartz is the most common gangue mineral, although in some deposits calcite, barite, and tourmaline are also present. Moreover, most of the copper veins contain galena, zinc blende, gold, and silver, and where these accessory ore minerals increase, the copper veins gradually change into true lead-zinc or gold-silver veins.

All the copper veins are genetically connected with acidic or intermediate igneous rocks such as granite, diorite, or corresponding effusive rocks, and none of them are accompanied by basic igneous rocks such as serpentine, gabbro, basalt, or diabase. Copper veins connected with granite or diorite seem to have been formed at high temperature and under high pressure. They are found mostly in the terrane of the Paleozoic or Mesozoic. Some of them contain skarn minerals, such as hedenbergite and garnet, as gangue minerals; others are accompanied by tourmaline, wolframite, and bismuthinite or contain cassiterite, forming copper-tin veins. All these hypothermal copper veins are small, and only a few of them are being worked at present.

A large number of copper veins now being worked belong to the epithermal deposits found in Tertiary liparite, andesite, and sedimentary rocks, which generally show signs of propylitization, sericitization, or silicification. Chalcopyrite occurs as the principal ore of these younger copper veins, and quartz is the predominating gangue mineral, although in some veins it is associated with much chlorite and micaceous hematite, especially in those veins found in the inner zone of northern Japan.

The copper veins may be divided into several kinds according to the associated minerals—(*a*) quartz copper veins, (*b*) siderite copper veins, (*c*) copper-tin veins, (*d*) tourmaline copper veins, and (*e*) copper vein with skarn minerals. The most typical of these veins are described below.

Quartz copper veins.—The quartz copper veins contain quartz as the principal gangue mineral, with or without calcite, fluorite, and barite, but with no high-temperature minerals such as tourmaline, garnet, or hedenbergite. The ore consists mostly of chalcopyrite, rarely tetrahedrite and enargite, together with pyrite, galena, and zinc blende. Important deposits belonging to this category are those now being worked at Ozaruzawa, Ani, Arakawa, Nagamatsu, Ashio, Ogoya, Ikuno, and Kinkaseki, of which those of the Ashio mine are especially noteworthy.

The Ashio mine is about 120 kilometers north of Tokyo. Geologically, the region is composed chiefly of liparite and Paleozoic formations, accompanied by granite, Tertiary sediments, andesite, and loam.

The veins are found mostly in liparite but also in the Paleozoic rocks adjoining liparite. There are two systems of parallel veins, one striking N. 60° E. and dipping 60° either north or south and the other striking N. 80° W. and dipping more than 60° S. Over 300 veins are known in all. Most of them are 0.5 to 10 meters wide and 100 to 1,000 meters long, but the principal vein (Yokomabu) has a length of 1,700 meters. This vein has been developed to a depth of 1,000 meters and is thought to continue still deeper.

The veins are of the quartz copper and chlorite-clay copper types. Most of the former are found near the surface and the latter in depth. In some places, however, they gradually pass into each other.

The quartz copper veins consist mainly of chalcopyrite, pyrite, pyrrhotite, and quartz, with galena, zinc blende, and arsenopyrite in small quantities. The chloritic-clay copper veins are formed of the same kind of ore minerals but contain chloritic clay as vein stuff.

Besides the true fissure veins, irregular deposits of chalcopyrite called "kajika" are found at the intersection of numerous radial veinlets or near the axes of folding in sedimentary rocks. The country rock consists of liparite and Paleozoic quartzite.

The "kajika" in liparite are five in number, and they occur in connection with other veins. The largest ore mass is that of "Kosei kajika" extending to a depth of 600 meters. The body of the "kajika" consists of sericitic and chloritic clays containing chalcopyrite scattered in large or small masses, with almost no pyrite or pyrrhotite.

The "kajika" in quartzite occur chiefly near the folding axis of the country rock. There are nine huge irregular masses, among which the "Sanbyakushaku kajika" is the largest, having a cross section of 1,500 square meters and a height of 250 meters. In general these masses consist mainly of chalcopyrite mixed with pyrrhotite and a small quantity of pyrite. The gangue is made up of clay.

The copper veins and the two kinds of "kajika" are not of different epochs but contemporaneous, having been created by the action of liparite eruption.

The Ashio copper mine is one of the largest of the quartz-vein type and has been worked since 1620. The ore averages 12.17 percent of copper and 37.40 percent of zinc. The production of copper in 1916–32 was as follows:

	Kilograms		Kilograms
1916–27	169,697,789	1930	14,062,972
1928	13,713,730	1931	14,714,066
1929	13,521,151	1932	14,778,919

Siderite copper veins.—The principal gangue minerals of the siderite vein type are calcite, dolomite, siderite, or other carbonates, with quartz and barite. The ore consists of chalcopyrite with pyrite, pyrrhotite, galena, zinc blende, etc., and contains small quantities of gold and silver. The most celebrated deposit of this type is that of the Omori mine.

The Omori mine is near the west end of Honshu, about 180 kilometers northeast of Shimonoseki. The region is composed chiefly of quartz-enstatite andesite and its agglomerate, with some propylite. A number of parallel veins occur in the andesite or near its contact with agglomerate. They all strike east and dip steeply north. The principal veins are the Sato-hi, Honnakase-hi, Uchinakase-hi, Sanjo-hi, and Umanose-hi. The Sato-hi, which is the chief lode of the mine, is traceable for more than 750 meters along the strike and 450 meters along the dip. The thickness ranges from a few centimeters to 3 meters or more. The ore consists of chalcopyrite locally mixed with zinc blende, galena, and hematite. It contains considerable gold and silver. The gangue minerals are chiefly siderite and barite, but some quartz is also present. The dressed ore contains on an average 0.00174 percent of gold, 0.0629 percent of silver, and 7.421 percent of copper. The deposit was discovered in 1300 A.D. and the mine became the most famous silver producer in Japan. At present, however, the rich ores are almost exhausted, and the mine was abandoned in 1927. The production in 1922–26 was as follows:

	Kilograms		Tons
1922 (copper)	144,776	1924 (ore)	163
1923 (copper)	38,933	1925 (ore)	299
		1926 (ore)	209

Copper-tin veins.—The third class consists of cassiterite veins, containing much copper ore, thus constituting sources of copper as well as of tin. The ore consists of cassiterite and chalcopyrite, with quartz as the gangue mineral, and is generally found in close relation with intrusive granite or diorite. The best-known mine of this type is the Akenobe.

The Akenobe mine is about 80 kilometers northwest of Kobe. The district consists of Paleozoic and Mesozoic sedimentary rocks, with such igneous rocks as diorite, porphyrite, andesite, and liparite. Innumerable veins occur, mostly in the Paleozoic and Mesozoic rocks, especially in green slate, and are also found in a dioritic rock. According to their strikes they may be divided into the Daisen vein group, or the veins striking northwest; the Daido vein group, or the veins striking north; and the Daijuko vein group, or the veins striking east. The Daisen vein, which is the main lode of this district, is continuous for more than 600 meters along its strike. Its width ranges from a fraction of a meter to 5 meters or more. The other veins are about 150 meters apart and are traceable for more than 300 meters along the strike. The ore consists of chalcopyrite, wolframite, and cassiterite, in places mixed with pyrite, bornite, zinc blende, galena, and native bismuth. The gangue consists chiefly of quartz. All the veins are composite and are considered to have been formed by five successive mineralizations—namely, (1) deposition of the main cassiterite ore, (2) deposition of wolframite-cassiterite ore, (3) deposition of chalcopyrite, (4) deposition of zinc blende, and (5) deposition of quartz with a little chalcopyrite. The ore contains on an average 9.04 percent of copper, 1.9 percent of tin, and 0.009 percent of silver. The mine was opened in 806 A.D. The production of ore in the 5 years 1928–32 was as follows:

	Tons		Tons
1928	11,900	1931	14,119
1929	675	1932	11,668
1930	14,428		

Tourmaline copper veins.—The tourmaline-bearing copper veins are generally connected with granite or allied plutonic rocks. They contain chalcopyrite associated with some wolframite, bismuthinite, and other sulphide minerals, with quartz and tourmaline as gangue minerals. The deposit of the Yakuoji mine is a good example of this type.

The Yakuoji mine is situated near the west end of Honshu, about 40 kilometers northeast of Shimonoseki. The monzonite and the Paleozoic sedimentary rocks are present in the mine in contact with each other. The deposit is near the contact zone, chiefly in monzonite though partly also in the Paleozoic rocks. There are many parallel veins, which strike north and dip 70° or more east. Eleven veins have so far been discovered, of which only two are now being worked. The veins are in general very thin, ranging from a mere streak to veins 70 centimeters in diameter. The chief ore mineral is chalcopyrite, and other sulphide minerals present are arsenopyrite, pyrite, bismuthinite, galena, and zinc blende. The most characteristic gangue mineral is tourmaline, but chlorite, scheelite, and quartz locally constitute notable parts of the veins. The ore contains on an average 8.0 percent of copper. Economically, the mine is very insignificant, the ore production being only 26 tons in 1929 and 49 tons in 1930.

Copper vein with skarn minerals.—A vein-formed contact-metasomatic deposit is found near the contact of acidic or intermediate plutonic rocks with the surrounding sedimentary rocks. The ore consists of chalcopyrite mixed with pyrrhotite and pyrite, and the gangue minerals are chiefly hedenbergite and garnet, with quartz and calcite. This deposit is worked at the Yoshioka mine.

The Yoshioka mine is about 150 kilometers west of Kobe. The rocks are Paleozoic and Mesozoic clay slates, sandstones, and schalsteins, traversed by serpentine and porphyrite. The deposit is a fissure vein in a phyllitic slate, partly replacing the country rock. There are 26 principal veins, running from northwest to southeast. The Hompi or main lode has been worked for about 900 meters in stope length, 250 meters in pitch length, and 2 meters in maximum width. The gangue minerals are quartz, calcite, hornblende, and fluorite; the ore consists of chalcopyrite, cupriferous pyrrhotite, arsenopyrite, zinc blende, and galena. Quartz and calcite are found in all veins, but hornblende is found only in the Hompi. The ore contains on an average 4.45 percent of copper and 0.007 percent of silver. This mine has been worked since 807 A.D. The production of copper in 1928 was 776,952 kilograms; in 1929, 72,520 kilograms; in 1930, 3,742 kilograms. In 1931 the mine yielded 501 tons of ore, but there was no production in 1932.

Other mines.—The production in the 5 years 1928–32 from the principal copper-vein mines in Japan not mentioned above is given in the following table:

Production from certain copper-vein mines in Japan, 1928–32

Mine	1928	1929	1930	1931	1932	Grade of ore (percent)	Geology
Akaishi .... ore (tons)	3,571	3,913	2,895	2,271	3,139	Cu 7.0.	Tertiary, liparite, andesite.
Unekura .... do	4,092	4,069	2,475	1,856	1,941	Cu 9.21, Ag 0.035	Do.
Tsuchihata .... do	11,130	17,407	14,402	8,936	9,513	Cu 15.3, Au 0.0001, Ag 0.003	Tertiary, liparite.
Washiaimori .... do	540	2,116	2,934	3,406	3,301	Cu 13.27, Ag 0.0117	Tertiary.
Mizusawa .... do	2,462	2,469	2,324	1,344	....	Cu 8.56	Paleozoic, Tertiary, liparite.
Ozaruzawa .. copper (kilograms)	3,405,126	3,869,858	4,983,857	5,715,573	5,890,676	Cu 6.67, Au 0.000016, Ag 0.00076	Tertiary, liparite, andesite.
Dobukai .... ore (tons)	2,120	3,377	3,649	2,566	1,661	Cu 6.89, Ag 0.0024	Tertiary, andesite.
Furokura .... do	1,085	2,065	2,145	....	....	Cu 9.663	Tertiary, andesite, liparite.
Ani .... copper (kilograms)	432,367	339,545	313,900	77,994	....	Cu 10.06	Tertiary, diorite, andesite, liparite.
Arakawa .... do	1,659,643	1,824,100	1,894,089	1,556,880	1,536,760	Cu 13.48	Tertiary, andesite, liparite.
Nagamatsu .... do	373,991	340,108	425,923	409,074	441,944	Cu 4.97	Tertiary, liparite.
Nikko .... ore (tons)	3,756	4,411	2,185	3,267	} 4,969	Cu 7.5	Do.
Tochigi .... do	2,201	2,201	4,546	2,490		Cu 5.68	Liparite.
Kawazu .... do	23,507	26,223	24,574	20,552	20,074	Cu 2.5, Au 0.0004, Ag 0.0269	Tertiary, liparite, andesite.
Ogoya ...... copper (kilograms)	1,683,440	1,644,600	1,704,000	1,054,676	1,393,397	Cu 2.11	Tertiary, liparite.
Ikuno .... do	4,858,523	6,050,399	6,824,721	6,645,892	6,495,547	Cu 3.05, Ag 0.0416, Zn 48.03, Sn 2.94	Mesozoic, Tertiary, liparite, andesite, basalt.
Okinoura .... do	16,631	15,700	18,084	10,881	9,099	Cu 1.6, Au 0.0015, Ag 0.0016.	Tertiary, andesite.
Eyomi .... do	7,110	7,067	5,798	46	....	Cu 2.78	Paleozoic.
Obie .... do	1,958	1,227	495	....		Cu 6.0	Paleozoic, quartz porphyry.
Kinkaseki .... do	....	....	....	1,383,709	1,620,124		
Kinkaseki .... ore (tons)	518	261	....	95,476	108,809	Cu 4.2	Tertiary, quartz andesite.

Distribution and geologic age of the copper deposits

The distribution of the principal copper deposits of Japan is shown on the attached map (pl. 39), on which their types are graphically represented.

Japan comprises four well-defined geologic as well as geomorphic provinces, all of which yield copper, although its distribution has been localized in certain parts of these provinces, as may be seen by examining the map. There is an abundance of cupriferous pyrite deposits in the outer zone of southern Japan, of contact-metasomatic deposits in the inner zone of the same region, of "kurokō" deposits in the inner zone of northern Japan, and of fissure veins in the inner zones of northern and southern Japan.

In the inner zone of northern Japan, where the Tertiary volcanic activity was extremely violent, are found extensive layers of younger Tertiary sediments composed chiefly of volcanic materials. Small intrusive bodies of liparite or andesite that are closely related to the deposition of the ores of the region are present here and there. The most productive copper deposits of the inner zone of northern Japan are the shallow copper veins and the "kurokō," which are widely distributed in the whole zone. The shallow veins and the "kurokō deposits form the chief sources of copper in Japan and seem to have been deposited from hydrothermal solutions following the eruption of liparite or andesite during late Tertiary time.

The outer zone of northern Japan contains four independent mountain blocks —Kwanto, Abukuma, Kitakami, and Hidaka—composed chiefly of gneiss, crystalline schists, Paleozoic and Mesozoic sedimentary rocks, and a considerable amount of intrusive rock. The zone as a whole is rather poor in copper, containing only a few contact-metasomatic and cupriferous-pyrite deposits. The Yaguki mine, in the Abukuma district, is the largest one on the contact-metasomatic deposits; the Hitachi mine, in the same district, is the only example of the cupriferous-pyrite deposits. Both contact and cupriferous-pyrite deposits in Abukuma are found in the Paleozoic sedimentary rocks or in the igneous rocks that pierce them. The age of intrusion of most of these igneous rocks is probably post-Carboniferous, although some of them are clearly Mesozoic, and the deposition of copper seems to have a close relation to the intrusion.

The inner zone of southern Japan is divisible into two subzones—the coastal subzone, along the Japan Sea, and the inland subzone. The coastal subzone is composed of Tertiary sedimentary rocks and of volcanic rocks ranging in age between late Tertiary and Recent. Its mineralization resembles that of the inner zone of northern Japan, and the most important feature consists of the fissure veins of epithermal origin. The copper deposits in this subzone seem to have a close relation to the late Tertiary volcanic activity.

The inland subzone of the inner zone has many characteristics which distinguish it from that along the coast. Granitic intrusive rocks occur extensively, but Paleozoic formations distributed without any order are found only in small areas. In this subzone there are contact-metasomatic deposits and hypothermal veins of copper, both of which contain high-temperature gangue minerals such as tourmaline, pyroxene, and amphibole. A few bedded replacement deposits of pyrite are also found, but the "kurokō" is quite unknown in the whole subzone.

The geologic age of the copper deposits of this subzone is not definitely determined. Most of them occur in Paleozoic rocks around the granitic intrusions, but a few are found in the Mesozoic rocks. The intrusive rocks that are intimately related to the genesis of the ore deposits are mostly post-Carboniferous and Mesozoic. The age of the deposits seems therefore to be late Paleozoic or Mesozoic.

The outer zone of southern Japan is composed of crystalline schists and Paleozoic and Mesozoic sedimentary rocks, which are arranged in belts running almost east and west. It contains many cupriferous-pyrite deposits, whose age is uncertain, though it is highly probable that most of them are pre-Carboniferous, because in the first place they are genetically related mostly to the basic or ultrabasic igneous rocks that intrude the crystalline schists underlying the so-called "Mikabu series," which is conformably covered by Carboniferous rocks; and in the second place these basic igneous rocks are metamorphosed together with the enclosing rocks into amphibolites and antigolitic and talcose schists, whereas the Carboniferous formation remains almost unchanged. There are also a few pyritic deposits of late Paleozoic or early Mesozoic age and a few of late Mesozoic or early Tertiary age. For instance, the bedded pyrite deposit of the Asakawa mine, which has replaced the radiolarian chert of the late Jurassic, may have some relation to the intrusion of basic and ultrabasic igneous rocks after Lower Cretaceous time.

In 1931, when the demand for copper was greatly diminished, 32.59 percent of the production in Japan came from the outer zone of southern Japan, 45.70 percent from the inner zone of northern Japan, 11.47 percent from the outer zone of northern Japan, and 10.34 percent from the inner zone of southern Japan. In the same year 43.29 percent of the copper production came from deposits older than the Mesozoic and 56.71 percent from those of the Tertiary.

AFRICA

Les minerais de cuivre en Angola (Afrique occidentale portugaise)

Par Fernando Mouta
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Le cuivre est connu sur presque toute la colonie de l'Angola, en des différents affleurements sans intérêt remarquable au point de vu économique. Parmi les plus importants nous distinguons Bembe et le sud d'Angola.

Bembe (district du Congo): Le cuivre est connu au Congo depuis une époque très ancienne. Les premiers navigateurs portugais au 15[e] siècle ont apporté déjà des nouvelles de l'existence des mines de cuivre exploitées par les indigènes. Le gisement se trouve dans les couches de la série schisto-calcaire (système du Bembe) dans une région où la géologie n'est pas encore bien détaillée. Il doit être d'origine interne, profonde; des altérations postérieures ont produit l'enrichissement de certaines zones, de préférence dans les niveaux calcaires (plans de stratification et de dislocation). Bien que des sulfures soient aussi connus (Serra da Canda), c'est la malachite le minerai qui est exploité. L'analyse (suivant B. Bebiano) montre la composition suivante:

	Pour cent
Cuivre	48.7
Oxydes de fer	1.6
Silice	6.3

La "Companhia das Minas de Cobre do Bembe," concessionnaire, a exploité en 1932 à peu près 1000 tonnes de minerai, dont la teneur varie de 44 à 52 pour cent.

Sud de l'Angola: Dans les zones littorale et subplanaltique du district de Mossâmedes, à Giraul, Pedra Grande et Chapéu Armado, sont connus des affleurements minéralisés dont la valeur économique n'est pas bien déterminé. Les roches y appartiennent au soubassement ancien, et les minerais se trouvent dans le contact du granite ou dans le voisinage, soit des carbonates (Pedra Grande), soit des sulfures (Vimpongos), parfois associés (Chapéu Armado).

Les gisements doivent avoir dans la plus part leur origine dans les agents minéralisateurs qui ont accompagnés l'intrusion de certaines roches éruptives plus récentes.

C'est ce qu'on voit dans la région du Haut Zambéze, où les travaux géologiques ont été entrepris soigneusement par la "Companhia Mineira do Alto Zambéze": un granite intrusif dans les couches du système du Bembe a minéralisé les schistes qu'il a traversé, et la malachite se trouve aussi dans une brèche granitique qui l'accompagne.

Au Congo, les roches éruptives plus récentes ne sont connues que plus au nord, dans la vallée du Zaire: un granite alcalin qui traverse les gneiss et les granites anciens. Les affleurements minéralisés de la région de Cuchi et Menongue ont certainement la même origine (granites amphiboliques post système du Bembe).

En dehors de ces affleurements, les plus importants, on connait encore des imprégnations cuivreuses dans les couches du système de Oendolongo (Cassinga), dans les calcaires du système du Bembe (Malange-Lutôe), dans les grès sublittoraux (Zenza do Itombe) et dans les grès de l'Albien inférieur (Dombe Grande).[1]

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[1] Pour les détails géologiques de la colonie de l'Angola voir Mouta, F., et O'Donnell, H., Carte géologique de l'Angola, Notice explicative (1 carte, 1:2,000,000, en couleures), Lisbonne, Ministère des Colonies, 1933.

Le bassin cuprifère du Katanga méridional

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La région du Katanga méridional, dans la zone sud de laquelle sont localisés les importants gîtes cuprifères katanguiens, est située à l'extrême sud-est du bassin hydrographique congolais. (Voir pl. 40.) Les grandes rivières qui la drainent, le Haut-Lualaba, la Lufira et la Haute-Luvua-Luapula, se déversent dans le Lualaba (nom donné au fleuve Congo dans sa zone d'amont) après avoir recoupé et traversé un large bourrelet en relief constitué par des formations géologiques anciennes rapportées aux formations cristallophylliennes et au complexe des Kibaras.

Ce bourrelet ancien qui borde au nord-ouest la région du Katanga méridional sépare cette région des zones appartenant à la grande plateforme congolaise voisine à laquelle elle est cependant rattachée actuellement par son système hydrographique. Il se dessine, en direction sud-sud-ouest à nord-nord-est, depuis le Zilo, ou plus exactement depuis l'ouest de Dikuluwe-Musonoi, jusque dans la zone de la Luvua, où il s'épanouit largement.

Plus au nord, il se prolonge suivant la bordure de la plateforme congolaise. Vers le sud-ouest, il subit un léger ennoyage.

Le bourrelet ancient intercalé entre le Katanga méridional et les régions de la plateforme congolaise a été soumis, tout comme ses prolongements, à des plissements successifs assez intenses de périodes anciennes encore insuffisamment définies, mais dont la dernière, particulièrement bien accentuée dans la région qui nous intéresse, se situe entre la période kibarienne et la période schisto-dolomitique.

Dans la région du Katanga méridional, qui s'étend jusque dans le Nord-Rhodésien et dont la bordure du nord-ouest est définie ci-dessus, on observe un ensemble de formations sédimentaires qui sont rapportées aux séries successives des deux systèmes suivants:

- Système du Kundelungu:
  - Série supérieure.
  - Série inférieure.
- Système schisto-dolomitique:
  - Série supérieure, ou série de Moashya.
  - Série inférieure, ou série dolomitique.

Tout le long du bourrelet du nord-ouest, ces couches viennent se présenter, en discordance de stratification, sur les formations anciennes souvent violemment plissées.

Les couches kundelunguiennes et schisto-dolomitiques reposant sur les formations anciennes du soubassement, ont rempli de leurs sédiments la cuvette du Katanga méridional et sont à peu près complètement seules à affleurer dans cette vaste région.

Tandis que dans toute la zone nord du Katanga méridional, elles ont généralement conservé leur allure calme primitive, apparaissant en couches horizontales ou légèrement ondulées, dans sa zone sud elles ont subi de violents plissements qui y dessinent un important bourrelet, plissé et arqué, dans lequel est incorporée la minéralisation cuprifère.

C'est sous l'action d'une poussée venant du sud, dont le prélude s'est manifesté dès le début de la période kundelunguienne et peut-être même un peu plus tôt, poussée qui semble avoir atteint son intensité maximum à la fin ou vers la fin de cette dernière période, que les couches qui remplissaient la partie sud de la cuvette katanguienne se sont érigées en massif plissé.

Gênés au nord-ouest par le bouclier stabilisé de l'ancien socle du Zilo-Manika, à l'est par un soubassement qui parait avoir été assez rigide, les plissements ont pris la forme arquée que nous voyons se dessiner dans le croquis géologique. Dans le massif ainsi plissé se dessinent des faisceaux anticlinaux et synclinaux successifs, qui ont affecté les couches du complexe schisto-dolomitique-kundelunguien et font apparaître les couches du système schisto-dolomitique dans les zones anticlinales et les formations kundelunguiennes sus-jacentes dans les bandes, plus larges, des synclinaux intercalaires. Dans les zones centrales du bourrelet plissé, la poussée, violente, a redressé les couches jusqu'à la verticale et même jusqu'au renversement, et les plis, dans les anticlinaux, passent souvent à la faille inverse amenant le chevauchement de la bordure du synclinal voisin. Les couches du système schisto-dolomitique, ou une partie de celles-ci, coincées dans les anticlinaux et dans leur zone faillée, y apparaissent souvent sous forme d'écailles, de noyaux, de paquets plus ou moins volumineux, parfois de grandes dimensions et entourés de brèches. Il faut observer de plus que vers la fin du paroxysme des plissements, se sont produits des charriages en cisaillement. Des accidents transversaux plus ou moins accentués affectent d'ailleurs le bourrelet et interrompent parfois eux aussi la continuité longitudinale des faisceaux de plis.

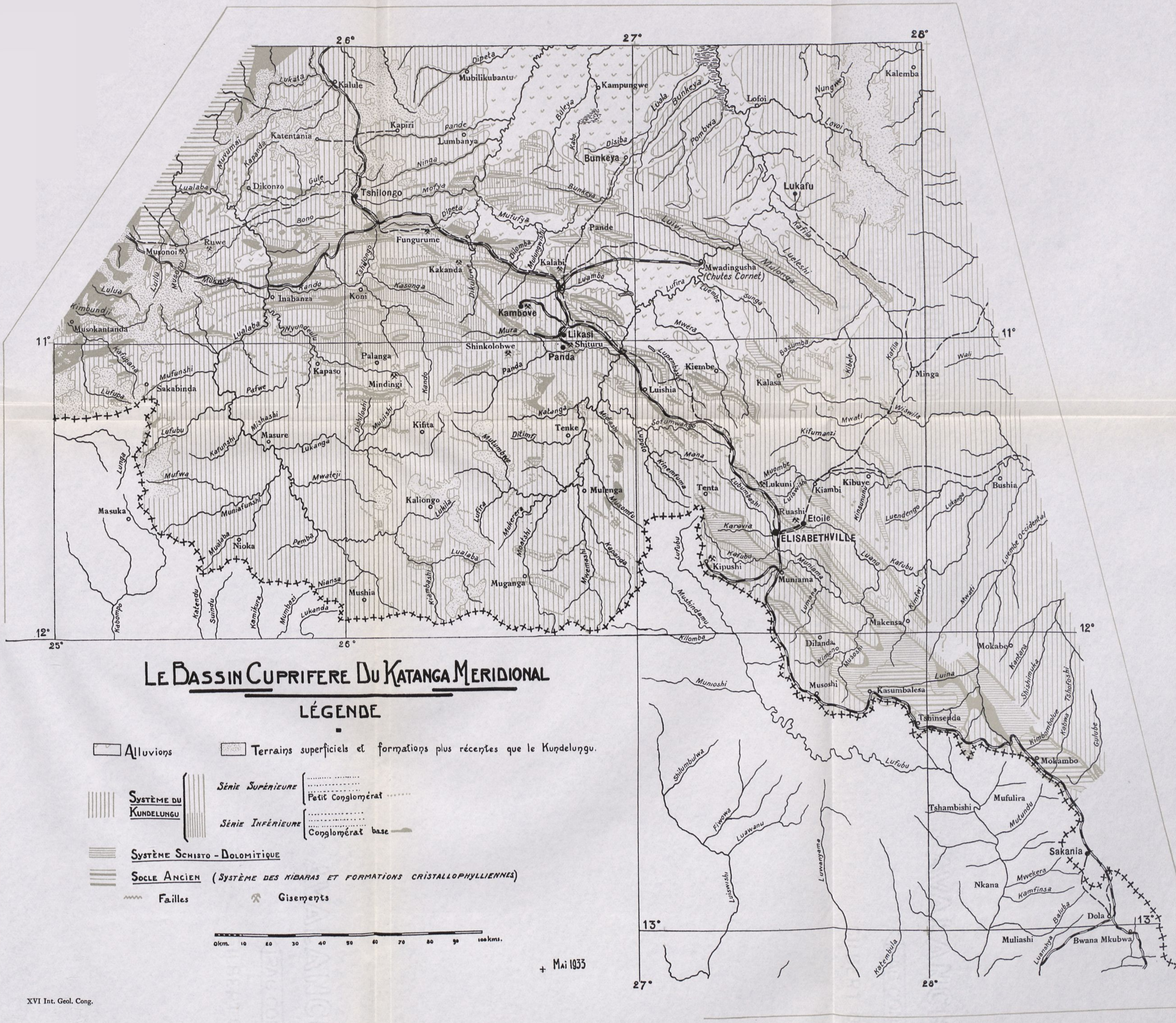
Nulle part dans le massif plissé du Katanga méridional on ne voit apparaître dans les anticlinaux, même les plus accidentés, les couches ou des éléments des couches du socle ancien qui pourraient y être coincées.

A l'extrême sud-est de l'arc plissé qui s'étend jusque dans le Nord-Rhodésien le soubassement ancien apparaît dans les plis et ceux-ci tendent à s'applatir et à s'évaser. Le soubassement ancien apparaît non seulement dans les anticlinaux, mais il s'étale même en larges plages décapées lorsqu'on pénètre dans le territoire rhodésien.

Dans cette zone sud-orientale, le socle ancien visible en affleurement montre qu'il a été affecté par les plissements kundelunguiens.

Le grand massif plissé de la zone sud du Katanga méridional pousse son énorme bloc accidenté jusqu'au delà de la ligne dessinée par la voie du chemin de fer du Katanga et par son prolongement de Tenge-Musonoi.

Plus loin, vers l'avant-pays, au delà d'une étroite bande relativement calme et où se dessine la plaine de la Mufufya-Lufira-Luembe, un dernier faisceau plissé s'érige en arc extérieur. C'est le bourrelet des Monts Koni, qui apparaît comme une vague avancée au front du vaste massif plissé katanguien.


Le Bassin Cuprifère du Katanga Méridional
Légende
Alluvions
Terrains superficiels et formations plus récentes que le Kundelungu.
Système du Kundelungu
Série Supérieure
Petit Conglomérat
Série Inférieure
Conglomérat base
Système Schisto-Dolomitique
Socle Ancien (Système des Kibaras et formations cristallophylliennes)
Failles
Gisements
0km. 10 20 30 40 50 60 70 80 90 100kms.
Mai 1933
25°
26°
27°
28°
11°
12°
13°
Kalule
Mubilikubantu
Kampungwe
Lofoi
Kalemba
Kapiri
Katentania
Lumbanya
Bunkeya
Dikonzo
Tshilongo
Lukafu
Pande
Musonoi
Ruwe
Fungurume
Kakanda
Kalabi
Mwadingusha
(Chutes Cornet)
Inabanza
Koni
Kambove
Musokantanda
Likasi
Shinkolobwe
Shituru
Panda
Palanga
Kapaso
Mindingi
Kiembe
Kalasa
Minga
Sakabinda
Luishia
Kifita
Masure
Tenke
Lukuni
Kibuye
Bushia
Kiambi
Tenta
Mulenga
Kaliongo
Ruashi
Etoile
Masuka
Elisabethville
Nioka
Kipushi
Muniama
Mushia
Muganga
Makensa
Mokabo
Dilanda
Musoshi
Kasumbalesa
Tshinsenda
Mokambo
Tshambishi
Mufulira
Sakania
Nkana
Dola
Muliashi
Bwana Mkubwa

Quoique dans ce faisceau avancé les couches soient encore redressées à la verticale dans les anticlinaux et que l'on voie apparaître dans ceux-ci les formations du schisto-dolomitique, l'action tectonique s'est cependant manifestée de manière moins violente que dans le grand massif du sud; les accidents y sont moins fréquents et moins intenses. Il semble bien que, dans cette zone frontale et dans son voisinage, l'on puisse discerner une tendance à la formation de diapirs, mais il faut pourtant attendre que des observations de détail plus complètes et plus serrées aient été faites dans cette zone pour pouvoir prendre une position définitive à ce sujet. L'un de nous (Robert) est d'avis que les noyaux, les paquets coincés des anticlinaux situés dans la zone minéralisée elle-même sont souvent de nature diapirique.

Lorsque partant des derniers anticlinaux du bourrelet du Koni, on passe à l'avant-pays et notamment à la région du plateau du Kundelungu, où les couches ont conservé leur horizontalité, ou tout au moins une allure calme, on observe que la pente des couches devient graduellement de moins en moins forte et que le passage des pentes de 90° à des pentes voisines de 0° se fait lentement, par transitions successives.

L'un des faits fondamentaux ayant permis, malgré l'absence de fossiles à signification chronologique, d'amener la géologie du Katanga méridional au point où elle est, a été l'établissement du raccord entre les couches du système du Kundelungu, horizontales dans la zone nord, et les mêmes couches incorporées dans le faisceau plissé de la zone sud. Cette notion, essentielle pour la géologie katanguienne, fut établie en 1921, vérifiée à diverses reprises en 1923 et 1924 et aussi plus récemment.[1]

Avec sa série supérieure, sa série inférieure et son conglomérat base, le système du Kundelungu resté le plus généralement horizontal ou ondulé dans la zone du nord, se retrouve parfaitement dans toute la zone violemment plissée du sud du Katanga méridional et du Nord-Rhodésien. Le grand faisceau plissé de ces régions avec ses venues cuprifères se rapporte bien à une période de mouvements tectoniques ayant eu leur paroxysme à la fin ou vers la fin de l'époque kundelunguienne. Ils sont nettement distincts et beaucoup plus récents que les mouvements tectoniques qui ont dessiné le bourrelet ancien, kibarien, du nord-ouest de la cuvette katanguienne. Ceux-ci ayant affecté le soubassement, ont eu leur dernière répercussion à l'époque post-kibarienne et anté-schisto-dolomitique et les venues stannifères notamment y sont liées. Le bouclier ainsi formé a cependant pu subir des répercussions atténuées lors du plissement kundelunguien. Il a dû rejourer plus ou moins, dans certaines de ses parties tout au moins, à la période de ces plissements et aussi lors de la formation du graben de l'Upemba et des petits gräben lufiliens comme semblent le montrer les failles longitudinales que l'on y trouve notamment en certaines zones de sa bordure du sud-est.

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[1] Robert, M., Sur la géologie du Katanga: Acad. roy. Belgique, Classe des sciences, Bull., 5e sér., tome 12, pp. 123–126, 1926; La géologie du Katanga méridional après la campagne 1926–27 du Service géographique et géologique du Comité spécial du Katanga: Soc. géol. Belgique Annales, Pub rel. Congo belge, annexe au tome 51, fasc., 2, pp. 55–67, 1928; Le Katanga physique, Bruxelles, Lamertin, 1927.

Le système du Kundelungu et le système schisto-dolomitique qui occupent la cuvette du Katanga méridional peuvent être caractérisés synthétiquement de la manière suivante:

Le système du Kundelungu:[2]

Série supérieure, épaisseur 4,000 à 4,500 mètres

Horizon des grès feldspathiques et schistes gréseux, épaisseur variable, 2,700 mètres environ. En bancs souvent épais. Intercalations de schistes gréseux et de schistes argileux. Ne semble pas être bien développé dans la zone sud du Katanga méridional.

Horizon des schistes gréseux, 500 à 700 mètres. Schistes à stratification irrégulière, ripple-marks, lentilles gréso-calcaires, lits de grès feldspathiques de plus en plus nombreux et importants vers le sommet de l'horizon.

Horizon des schistes argileux, 500 à 700 mètres (parfois 400 à 800 mètres). Finement stratifiés (avec horizons et lentilles gréso-calcaires et horizons de schistes gréseux intercalés), parfois, surtout dans la zone sud, sont envahis par des calcaires, des calcaires gréseux légèrement feldspathiques et des lentilles.

Niveau de cherts parfois oolithiques, 1 mètre.

Schistes argileux avec tendance au passage à l'horizon des schistes gréseux, 150 à 300 mètres.

Niveau calcaire oolithique à algues,[3] 0 à 3 mètres, ou plus.

Schistes argileux, 300 à 500 mètres.

Calcaire rose, 5 à 20 mètres. Dolomitique à grain fin.

Petit conglomérat, 0 à 20 mètres (parfois jusque 30 mètres). A petits cailloux roulés, souvent des agates.

Série inférieure, épaisseur 600 à 1,200 mètres:

Calcaire gréseux, ou grès calcareux, 300 à 500 mètres (parfois moins). Lentilles gréso-calcareuses.

Schistes argileux, 200 à 400 mètres. A schistosité irrégulière, souvent chloriteux.

Calcaire de Kakontwe,[4] 40 à 60 mètres (parfois 0 à 400 mètres):

Horizon supérieur, dolomie brunâtre à grain fin.

Horizon inférieur, calcaire gris, microcristallin, veinules de calcite.

Grand conglomérat base glaciaire, 100 à 300 mètres. En bordure de la cuvette le conglomérat peut être envahissant vers le haut.

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[2] Cornet, J., Les formations post-primaires du bassin du Congo: Soc. géol. Belgique Annales, tome 21, pp. 193–278, pl. 5, 1893. (Nom donné aux couches schisto-gréseuses horizontales des plateaux de la zone nord du Katanga méridional.)

Robert, M., Le système du Kundelungu au Katanga: Soc. géol. Belgique Annales, Pub. rel. Congo belge, annexe au tome 39, 1912. (Nom donné à la série schisto-gréseuse prolongée vers le bas par la série schisto-calcaire et jusques et y compris le conglomérat glaciaire de base de la zone nord du Katanga méridional.)

Robert, M., La géologie du Katanga méridional après la campagne de 1926–27 du Service géographique et géologique du Comité spécial du Katanga: Soc. géol. Belgique Annales, Pub. rel. Congo belge, annexe au tome 51, fasc. 2, p. 55, 1928. (Nom donné aux mêmes couches reconnues dans la zone sud du Katanga méridional et incorporées dans le faisceau plissé kundelunguien de cette région.)

[3] Algues fossiles, niveau de position stratigraphique certaine. Choubert, B., La découverte d'algues dévoniennes dans le niveau du calcaire rose du Katanga: Soc. belge de géologie, séance du 15e décembre 1931.

[4] Algues fossiles. Le niveau des échantillons dans lesquels ont été trouvées ces algues est de position stratigraphique douteuse. Hacquaert, A. L., Ontdekking van fossiele groenwieren in het calcaire rose (Kundelungu system) van Katanga: Natuurw. Tijdschr., 13 jaargang, no. 3 a 5, Gand, 1931.

Le système schisto-dolomitique: Dans les zones du Katanga méridional, où les plissements sont violents et fortement accidentés, le système schisto-dolomitique affleure en bandes souvent étroites coincées dans les anticlinaux, bandes dans lesquelles on peut distinguer deux sortes d'affleurements.

Immédiatement sous le grand conglomérat glaciaire du Kundelungu, apparaissent les couches de la série supérieure schisto-dolomitique. Elles sont en position normale et en succession régulière et concordante sous ce conglomérat.

La succession, régulière depuis la base du conglomérat kundelunguien, est interrompue, vers le bas de la série et vers l'axe de l'anticlinal, par un accident concrétisé par une brèche. On passe alors aux paquets axiaux, entourés de brèches et apparaissant sous forme d'écailles, de noyaux, de paquets parfois très volumineux. On y trouve des horizons qui appartiennent à la série inférieure du schisto-dolomitique, mais dont la position dans cette série ne peut pas être définie. Les couches de ces paquets ne prolongent pas nécessairement, en continuité, la succession des horizons réguliers de la série supérieure observée en place. De plus, les paquets axiaux, entourés de brèches et coincés, ayant pu, dans les plis fortement accidentés, être arrachés soit au flanc sud ou au flanc nord de l'anticlinal profond, peuvent montrer une succession normale ou renversée.

La brèche qui sépare la série supérieure en position normale des paquets axiaux, ne se trouve pas nécessairement localisée à un niveau constant. En tout cas, dans la zone externe du grand massif plissé, elle apparaît, en général, immédiatement en dessous de l'horizon cherteux.

Les observations effectuées dans la région intérieure du faisceau plissé katanguien donnent le libellé de la colonne 1 du tableau suivant (vis-à-vis de p. 708).

Dans le bourrelet du Mont Koni, dernière vague voisine de l'avant-pays et où l'intensité des accidents est fortement atténuée, la série supérieure du schisto-dolomitique, continue et régulière, se présente comme l'indique la colonne 2 du tableau, selon les observations effectuées par Cornet, Robert, Timmerhans, Van den Brande, Dubois et Grosemans.

A l'extrémité sud-est de l'arc plissé, à proximité de la frontière Katanga-Rhodésie, le système schisto-dolomitique, observé depuis le soubassement, est figuré dans la colonne 3 du tableau.

Enfin, dans la zone rhodésienne voisine, le schisto-dolomitique se présente comme l'indique la colonne 4 du tableau.

Nous considérons la minéralisation cuprifère du Katanga méridional et du Nord-Rhodésien comme étant liée aux mouvements orogéniques kundelunguiens, aussi serait-il d'un grand intérêt de pouvoir fixer l'âge de ces mouvements.

Les fossiles trouvés dans les couches du système du Lualaba-Lubilash et qui rapportent au Permien la série inférieure de ce système, permettent de considérer que le système du Kundelungu ainsi que les plissements qui l'ont affecté au Katanga méridional sont antérieurs à l'époque permienne.

Des essais de raccord, basés sur des positions relatives et sur des aspects lithologiques, avec les formations de l'Afrique australe, raccords qui ne peuvent bien entendu donner que des résultats approximatifs et provisoires, permettraient de paralléliser le système schisto-dolomitique et le système du Kundelungu, respectivement avec le système du Transvaal et le système de Waterberg, qui pour certain correspondrait au système du Cap. Le Kundelungu aurait ainsi tendance à se situer vers la tête du Silurien, le Dévonien et la base du Carbonifère, comme l'admet l'un de nous (Robert).

Les algues fossiles signalées dans le schisto-calcaire du Bas-Congo par M. Cayeux et dans les calcaires du Kundelungu du Katanga par MM. Hackaert et Choubert n'ont pas jusqu'ici de signification chronologique bien nette.

L'un de nous (du Trieu), se basant notamment sur l'absence de fossiles à signification chronologique, tend plutôt à se rallier à l'idée que cet ensemble pourrait être considéré comme précambrien.

Les gîtes cuprifères du Centre africain se localisent dans la bande de territoire où se déroule le vaste faisceau arqué des plis kundelunguiens. De la région de Bwana M'Kubwa en Rhodésie, au sud-est, jusque dans la zone de Musonoi-Dikuluwe, à l'ouest, les gîtes se succèdent sur une longueur de quelque 500 kilomètres et sur une largeur de 100 kilomètres. Les principaux de ces gisements sont figurés sur le croquis géologique et se rapportent aux groupes suivants: En Rhodésie, Bwana M'Kubwa, Roan Antelope, N'Kana, Mufulira, N'Changa; au Katanga, Kipushi, l'Etoile, Ruashi, Lukuni, Luishya, Likasi, Shituru, Kamatanda, Kambove, Tantara, Fungurume, Kakanda, Mindingi, Kolwezi, Musonoi, Dikuluwe.

Les concentrations cuprifères que l'on peut observer au Centre africain sont le résultat d'une série, sans aucun doute complexe, de phénomènes qui se sont manifestés durant de longues périodes géologiques et qui, superposant leurs effets, permettent assez malaisément de dégager avec précision ce qui revient à chacun d'eux.

Depuis leur mise en place par venues de profondeur d'origine magmatique, les gisements cuprifères ont subi, durant de longues périodes, des actions secondaires d'altération et des remises en mouvement qui ont provoqué des migrations minérales, étendant la minéralisation à des roches encaissantes primitivement stériles et enrichissant certaines zones. Ces actions secondaires rendent parfois assez difficile la détermination de l'allure et de l'extension primitive de certains gîtes.

Il faut observer en tout cas que tous les gîtes du Katanga au nord du 12° parallèle, montrent un développement considérable de la zone d'oxydation. L'épaisseur en atteint couramment 40 mètres et plus. La relation avec la position actuelle du niveau hydrostatique dans les divers gîtes est loin d'être constante, quoique souvent les minerais carbonatés disparaissent en moyenne à quelques mètres sous le niveau d'eau. Mais il y a lieu de tenir compte dans certains cas des circulations profondes et peut-être aussi des anciens niveaux locaux de la nappe aquifère. C'est ainsi qu'au gisement de Kolwezi nous trouvons des carbonates à plus de 200 mètres sous le niveau hydrostatique.

La malachite et la chrysocolle se trouvent sous toutes les formes que peut suggérer une remise en mouvement, par circulation d'eau météorique descendante, imprégnation, concrétions, enduits zonaires, formations stalactitiques, cristallisations dans les cavités, etc.

On n'observe pas de variations systématiques des teneurs suivant la verticale pour un même gisement, la teneur moyenne de l'ensemble des minerais de la zone d'oxydation se maintient sensiblement constante.

Système schisto-dolomitique

1	2	3 (Sud-Katanga)[a]	4 (Rhodésie)[b]
500 à 700 mètres: Horizon de schistes et calcschistes zonés-rubanés, parfois bancs de quartzite feldspathique, 300 mètres. Schistes noirs pyriteux, 100 à 200 mètres. Schistes gréseux dolomitiques calcaro-gréseux, 100 à 200 mètres. Petit conglomérat, 0 à 10 mètres. Horizon cherteux et ferrugineux; jaspes; oolithes siliceux, 5 à 10 jusque 60 mètres.	Schistes et calcschistes en plaques, 1 à 10 mètres. Banc de quartzite feldspathique, 15 à 70 mètres. Schistes gris-verts, 100 à 150 mètres. Schistes noirs pyriteux, 100 à 200 mètres. Schistes gris-verts gréseux-dolomitiques, 100 à 200 mètres. Petit conglomérat, 1 à 10 mètres. Schistes dolomitiques gris-verts, 50 à 85 mètres. Cherts, oolithes siliceux-jaspes, 3 à 5 mètres.		400 à 600 mètres: Gres feldspathiques, ±15 mètres. Schistes noirs. Schistes avec intercalations gréseuses. Cherts et oolithes, jusque 5 mètres.
Série des mines, 150 à 200 mètres: Calcaire dolomitique ou dolomies en gros bancs, peu silicifiées. Terres noires ou sables. Schistes dolomitiques avec bandes graphiteuses. Schistes argileux, terres noires à la base. Banc de calcaire dolomitique peu silicifié. Calcaire dolomitique recristallisé et silicifié. Roche cellulaire. Calcaire dolomitique à bandes certeuses. Roche siliceuse feuilletée.	200 mètres: Schistes dolomitiques gris-verts, 5 à 20 mètres. Dolomies rosées, 5 à 15 mètres Dolomies cristallines blanches 15 à 40 mètres. Schistes noirs, 1 mètre. Dolomies cristallines blanches ou bleues, 100 à 200 mètres.	Schistes dolomitiques et dolomies (parfois les calcaires) renfermant quelques niveaux gréseux, 300 mètres. Schistes argileux en partie dolomitiques, alternant avec des grès et des quartzites feldspathiques, 300 mètres.	550 à 600 mètres: Dolomies et schistes avec intercalations de grès.
		Quartzites feldspathiques et grès feldspathiques, parfois conglomératiques, renfermant quelques bancs schisteux, 250 mètres. Cherts et roches hématitisées métasomatiques, 20 mètres. Grès arkosiques, grès vacuolaires, grès quartzo-sériciteux et quartzites séериciteux, 30 mètres. Conglomérat arkosique, alternant avec des bancs de grès et de schistes gréseux micacés, 100 mètres.	±400 mètres: Schistes, grès et dolomites, 175 mètres. Grès feldspathiques Grès et conglomèrat } 175 mètres

Soubassement (cristallophyllien et kibara).

[a] Gysin, M., Recherches pétrographiques dans le Haut Katanga, note 3, Les formations de la série de Roan: Soc. phys. et hist. nat. Genève Compt. rend., vol. 50, no. 1, janvier-mars, 1933.
[b] Gray, Anton, The correlation of the ore-bearing sediments of the Katanga and Rhodesian copper belt: Econ. Geology, vol. 25, pp. 783–804, 1930.

L'étude par sondage des parties profondes des gîtes montre que la répartition de la minéralisation oxydée n'a généralement que de très lointains rapports avec celle de la minéralisation sulfurée primitive. Il y a eu non seulement altération des sulfures en carbonates ou silicates mais remise en mouvement de ces minéraux.

Notons que les affleurements se présentent de manière quelque peu différente dans la zone centrale de la cuvette du Katanga et dans la zone minéralisée de l'extrême sud-est, au voisinage de la frontière rhodésienne et en Rhodésie. Dans la première région, les couches sur lesquelles portent la minéralisation sont surtout constituées par d'importantes masses de calcaire dolomitique. Aussi le minerai y est-il retenu en partie au voisinage des zones superficielles, formant de longs affleurements, surtout de carbonates de cuivre, très visibles et aisément repérés. Dans la 2^e zone, les couches minéralisées étant plutôt schisto-gréseuses, le minerai est généralement entré plus facilement en dissolution, laissant les affleurements lavés et appauvris au point d'être parfois difficilement décelables par des prospections superficielles rapides.

Au Katanga les zones accidentées et minéralisées montrent l'action très nette d'un métamorphisme hydrothermal, mais jusqu'ici on n'a trouvé nulle part d'intrusions magmatiques nettement en liaison directe avec les gîtes. Dans les anticlinaux, où l'on observe de la minéralisation, les zones qui paraissent avoir été les plus propices aux venues minéralisantes sont celles où l'on trouve les noyaux à allure diapirique constitués par les couches carbonatées de la série des mines.

L'un de nous (Robert) estime que la minéralisation primaire dans le district cuprifère katanguien est un phénomène assez complexe lié aux phases du plissement kundelunguien. Cette minéralisation a pu commencer à se manifester par venues diffuses, lors de la formation en profondeur des premiers plis. Elle a dû se porter sur des zones localisées, particulièrement accidentées et s'y intensifier par la suite.

La minéralisation intensifiée s'est portée notamment vers le faisceau de plis situé vers la zone moyenne externe du grand bourrelet plissé. Dans ce dernier faisceau de plis, les sections des zones anticlinales où apparaissent des blocs ou des paquets coincés, constituant de véritables diapirs, ont dû être en tout cas plus propices à la localisation de la minéralisation que les parties anticlinales voisines qui se présentent en étreintes stériles.

Les paquets diapiriques, minéralisés ou non, ont été mis définitivement en place lors du paroxysme des plissements kundelunguiens.

Il faut observer d'autre part qu'à la période de paroxysme de plissement, les couches kundelunguiennes elles-mêmes, quoique élevées dans la série des formations plissées, ont pu subir des fissurations très accidentées permettant la propagation des venues minéralisantes et donnant ainsi jusque très haut et loin du magma, de la minéralisation à tendance filonienne. C'est dans cette dernière minéralisation que l'on trouve le plomb et le zinc à côté du cuivre. Les charriages en cisaillement de la fin de la période de plissement ont pu déplacer des massifs entiers avec leur minéralisation.

C'est à la minéralisation à tendance filonienne et datant de la période de paroxysme des plissements que l'on a affaire le plus généralement dans les pointements minéralisés situés en dehors de la bande arquée diapirique dont il est question plus haut.

Notons par ailleurs que l'étude détaillée des gîtes du Katanga méridional et l'examen des minerais de profondeur n'ont cependant pas permis d'observer jusqu'ici des phénomènes de minéralisations primaires successives nettement séparées en un point donné. En outre les caractères en général très uniformes de la minéralisation sur une superficie considérable semblent se concilier assez mal avec l'hypothèse de minéralisation s'étendant sur de très longues périodes. C'est pourquoi tandis que le premier d'entre nous défend la thèse du déplacement de paquets déja entièrement ou partiellement minéralisée dans les blocs diapiriques lors du paroxysme et parfois charriés ensuite; le second estime plutôt que la minéralisation du Katanga a pu constituer un phénomène relativement bref se situant après l'ère des grands mouvements kundelunguiens.

En ce qui concerne la nature du magma profond, source première des minéralisations du bassin cuprifère Katanga-Rhodésie, il nous paraît prématuré de vouloir résoudre la question. Nous ne prendrons donc pas position à ce sujet.

En Rhodésie, où le soubassement ancien apparaît assez largement, on tend à admettre que les venues sont toujours en relation avec certains granites relativement récents dont on constate la présence au voisinage des gisements. On peut toutefois se demander si le rôle de ces granites n'est pas quelquefois différent de celui que l'on pourrait lui attribuer à première vue.

La présence des intrusions granitiques créant des zones d'hétérogénité dans le complexe sédimentaire soumis au plissement, il serait normal que ces zones constituent des lieux d'élection pour les anomalies tectoniques et qu'elles aient permis aux venues minéralisantes émanées du magma profond de se répandre dans certaines formations favorables.

Au Katanga, dans la partie sud-est du bassin cuprifère, les conditions sont analogues à celles que l'on observe dans la région rhodésienne voisine. On y trouve aussi la présence de granites dont certains ont pu affecter des couches relativement élevées dans l'échelle stratigraphique, notamment les couches du Kundelungu inférieur. Par contre, dans tout le restant de la zone katanguienne, à côté de manifestations magmatiques acides lointaines les seules manifestations magmatiques directes reconnues sont des intrusions basiques dont on observe la présence dans certains anticlinaux faillés, intrusions dont la venue est postérieure au dépôt des couches du Kundelungu. Il nous parait, en tout cas, qu'une minéralisation partielle tout au moins devait être rattachée à ces venues basiques. On doit supposer que les plissements à leur paroxysme ont facilité l'établissement des communications entre le magma profond et les régions plus superficielles de l'écorce terrestre.

Les grands gîtes du type Katanga normal, c'est-à-dire ceux qui sont encaissés dans les couches carbonatées de la série des mines, au sens strict des géologues de l'Union Minière, et qui s'incorpore dans la série inférieure du système schisto-dolomitique, montrent toujours l'association cuivre-cobalt. Cette association se retrouve en Rhodésie. De plus, au Katanga la présence de l'uranium a été signalée dans un nombre suffisant de gîtes pour que l'on puisse considérer cet élément comme faisant partie de la minéralisation normale.

Un certain nombre de gisements, bien que présentant les mêmes caractéristiques stratigraphiques et tectoniques que les précédents, s'en distinguent par la nature plus spéciale de la minéralisation. Ce sont notamment:

Shinkolobwe, où l'on trouve l'association d'uranium, cuivre, cobalt, nickel et molybdène avec apparition de minéralisations en or et métaux du groupe du platine. Le nickel, qui dans les gîtes de cuivre normaux est presque inconnu, prend ici un grand développement.

Ruwe, où l'on trouve en plus du cuivre et du cobalt, le vanadium, l'or et les métaux du groupe du platine.

Quant au gîte de Kipushi, dans lequel le plomb et spécialement le zinc apparaissent en grande abondance en même temps que l'argent, il constitue jusqu'à présent un cas unique. C'est un gisement de métasomatose formé dans les calcaires de la base du Kundelungu, au contact d'une faille liée à un grand accident l'allure longitudinale. On y constate l'absence totale du cobalt et de l'or.

Dans les gîtes normaux que les sondages ont permis de reconnaître en profondeur, on constate que la minéralisation primaire se trouve sous forme de chalcopyrite associée au sulfure de cobalt et à la pyrite de fer.

Les sulfures riches et notamment la chalcosine et la bornite qui se rencontrent dans les parties hautes des gisements sont le résultat d'un enrichissement par voie descendante. Il est d'ailleurs a remarquer que dans les gîtes de ce type, à minéralisation disséminée dans une gangue essentiellement carbonatée, il n'existe pas de zone de cémentation générale. On passe brusquement de la zone d'oxydation à la zone primaire. Il ne peut y avoir de cémentation que là où la masse de sulfure était suffisamment importante par rapport à la gangue, ou là où la couche encaissante s'est trouvée suffisamment modifiée par les phénomènes marquant la minéralisation primaire pour se trouver relativement inerte à l'action des solutions cuprifères.

Dans un grand nombre de gîtes, la minéralisation primaire se localise de préférence dans ce que l'on appelle la "formation à minerai vert." Il s'agit en fait d'une zone de friction sensiblement interstratifiée qui se trouve au contact inférieur de dolomies de la série des mines. On y observe un développement considérable de minéraux de la famille des chlorites. C'est dans cette formation du minerai vert que l'on observe les phénomènes de cémentation les plus réguliers.

La minéralisation primaire ne s'est pas limitée à cette formation du minerai vert. Elle s'étend graduellement jusqu'à une certaine distance dans les formations dolomitiques voisines et ceci spécialement dans les parties fracturées. Au gisement de Luishia, la zone ainsi minéralisée atteint la puissance exceptionnelle d'environ 40 mètres.

Les minéralisations superficielles à caractère oxydé intéressent en général une épaisseur de formation beaucoup plus importante. L'épaisseur des couches de la série des mines, au sens strict, est de l'ordre de 200 mètres. Toutes les couches qui en font partie ont été minéralisées à un degré plus ou moins accentué. Dans le cas de ces minéralisations de nature secondaire, l'influence des roches encaissantes et spécialement le degré de porosité des roches après altération se fait particulièrement sentir. C'est dans cette zone d'oxydation que l'on trouve notamment ces terres noires à minerai en grains et ces roches cellulaires qui ne sont que le résidu de l'altération de calcaires dolomitiques et qui sont caractéristiques des chapeaux oxydés du Katanga.

Ces phénomènes de remise en mouvement superficiel ont accentué l'apparence stratifiée des gîtes, ce qui, pour un observateur non averti, donne l'impression première de gîtes d'origine sédimentaire.

The Northern Rhodesia copper belt

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Introduction

The Northern Rhodesia copper belt has emerged within a few years from a bush-covered African wilderness to a region of industrial activity. Extensive ore reserves have been developed, towns constructed, branch railroads built, and copper plants erected. The region is now the world's greatest copper district; three large mines, the Roan Antelope, N'Kana (Rhokana), and Mufulira, are producing, and other important ones have been held back owing to the world economic depression.

The unique deposits themselves are of no less interest than their rapid development. They constitute a new type among large-scale copper deposits, and their points of dissimilarity to the "porphyry coppers" are more numerous than their similarities.

Geography

Location and access.—The Northern Rhodesia copper belt lies in south-central Africa, at about 12°45′ south latitude (fig. 107). It forms a northwestward-trending strip about 140 miles long by 40 miles wide, adjacent to the Katanga boundary of the Belgian Congo.

The region may be reached by railway from Cape Town (2,159 miles); from Lobito Bay, in Portuguese West Africa (1,445 miles); and from Beira, on the East African coast (1,450 miles); or by rail and water from Dar-es-Salaam, in Tanganyika. N'Dola, on the main line of the Congo-Rhodesian Railway, is the distributing center from which branch lines extend to Roan Antelope (22 miles), to N'Kana (45 miles), and to Mufulira (14 miles beyond N'Kana).

FIGURE 107.—Index map showing location of Northern Rhodesia copper belt. (Courtesy of Rhodesian Selection Trust, Ltd., and Economic Geology.)

Physical features.—The region is part of the great African plateau, which here lies at an altitude of about 4,000 feet. The flattish surface is broken here and there by widely separated shallow stream depressions or rare kopjes (hills) that form monadnocks on this slightly dissected peneplain. From the top of one of these kopjes one may gaze for miles in all directions over a monotonous, undulatory surface of acacia tree tops. The divide between the Congo and Zambesi drainage basins, which is also the boundary between Katanga and Northern Rhodesia, can hardly be discerned by the eye; only by careful leveling can it be located.

Streams are few, narrow, and widely spaced. The Kafue River and its tributaries, a part of the Zambesi system, drain the copper belt. For the most part the Kafue Valley is broad and shallow, but in places it has slightly entrenched its old meanders to form shallow but steep ravines. The tributaries likewise occupy broad, almost imperceptible valleys, which are commonly swampy near their headwaters. The region is poorly drained; the rains give rise to shallow ponds and numerous swampy areas.

The surface is mantled by a deep regolith, and outcrops are few. Forests cover most of the land, but here and there the forest opens into enclosed grassy areas (dambos). Underbrush is scanty and trees are widely spaced, so that the region presents the appearance of a great park. Travel through it is simple.

Climate.—The low latitude is compensated by altitude, and the climate is pleasant for white folks. There are two seasons, a dry and a rainy. About 50 inches of rain falls between November and April (summer), when grasses grow luxuriantly and swamps and dambos become flooded. In the succeeding dry season (winter) continuous sunshine prevails, the days are warm, the dambos dry up, and small streams cease. The temperature throughout the year ranges from freezing to 96° F.; the average is around 70° F. The nights are always cool, even in summer, and in winter they are unpleasantly chilly, with occasional frosts. The malarial mosquito has been eliminated in the vicinity of the mines.

History and production

Oxidized copper ores have long been known in Northern Rhodesia. Work commenced on them at the old Bwana M'Kubwa mine in 1903 (2); copper shipments started in 1913, and after intermittent operations this mine was closed. Such low-grade Rhodesian oxidized ore compared unfavorably with the rich ore of Katanga. Then sulphides were discovered by boring at N'Changa, but as they were mixed with oxides, their significance was not realized, and it was not until a sulphide zone had been penetrated at Roan Antelope, in November, 1925, that their importance was appreciated (8). Later the N'Kana, Mufulira, Chambishi, Baluba, and Extension deposits were discovered.

Intensive mine development began in 1927, and copper production at the Roan Antelope began in 1931. The Rokana (N'Kana) made its first production in December, 1931, and the Mufulira in 1933. To the end of 1934 the district produced 12,276,385 tons of ore, yielding 356,300 tons of copper.

Geologic setting

Rock formations

Geologically similar conditions prevail throughout all of the Northern Rhodesia copper belt (fig. 108). The ores occur in sedimentary beds underlain by metamorphic and intrusive rocks and overlain by a great thickness of clastic sediments. There are later intrusions of igneous rocks. Folding has produced anticlines and synclines. The anticlines have been eroded, exposing the underlying rocks, but parts of the synclines have been preserved, and it is in these synclinal remnants that the copper deposits occur.

As the region is covered by a deep regolith, and outcrops are few, the areal geology has been determined chiefly from pits, drill holes, soil, vegetation, and mine workings.

Geologic column.—The general geologic column (7) for the copper belt is as follows:

Intrusive rocks:
 Gabbro and diabase sills and dikes.
 Younger gray granite.
Katanga system:

Kuṇdelungu series:	Meters	
Upper group	2,000±	
Lower group	2,000±	
		4,000
Mine series (Série des Mines):		
M'Washia group	400–600	
Upper Roan group	550–600	
Lower Roan group; copper	350–600	
		1,500

Unconformity.
Granite intrusives.
Muva system.
Unconformity.
Lufubu system.

Older systems.—The Lufubu and Muva systems consist of ancient schists and gneisses, which, together with the older granites, form a basement complex upon whose eroded surface were laid unconformably the sediments of the Katanga system.

Katanga system.—The Katanga is the economically important system of central Africa, as it includes the Série des Mines, which contains the copper deposits of Northern Rhodesia and of Katanga.

The Série des Mines, or Mine series, was first studied and named in Katanga and is the equivalent of the Bwana M'Kubwa series of Bancroft (1) and Jackson (13) and of the original Roan series of Gray (2), who later (5) made a correlation, adopted the term "Mine series," and subdivided it into three groups.

The Lower Roan group is the ore container of Northern Rhodesia but is not exposed in the main central part of the Katanga belt. It consists of altered continental feldspathic sandstones, sandstones, and conglomerates, with some thin beds of shale and dolomite. The large copper deposits are confined to the lower part of this group. The beds have undergone some metamorphism.

The Upper Roan group consists of dolomite and dolomitic shale, with some interbedded sandstones, and includes the ore dolomites, which in Katanga contain the great copper deposits. These beds rarely crop out in Rhodesia and are exposed only by drill holes and test pits. A little copper occurs in these beds in Rhodesia.

The M'Washia group consists principally of shales, with local dolomitic beds and persistent sandstones at several horizons. These beds also contain copper in Katanga and a little in Rhodesia.

The Kundelungu series conformably overlies the Mine series. It is widespread in Katanga and well known in Rhodesia. At its base is the so-called "tillite of the Katanga," followed by a succession of dolomite, dolomitic shales, sandstone, and feldspathic sandstone. Then follow the "Petit conglomerate," limestone, shale, and sandstone.

Later intrusives.—The rocks of the Katanga and earlier systems are cut by a "younger gray granite," the intrusion of which was accompanied by the Rhodesian copper mineralization. A younger red granite (N'Changa red granite)(13) also intrudes the same systems, but its relationship to the gray granite is unknown. Dikes of aplite and pegmatite, some of which contain copper, accompanied the granitic intrusions.

The basic intrusions are mostly in the form of sills and are considered to be later than the folding of the Roan group (7, p. 322).

Age of formations.—The pre-Katanga rocks are generally regarded as of pre-Cambrian age. Uncertainty exists as to the age of the rocks of the Katanga system. Bancroft (2, p. 3) groups the Mine series under the pre-Cambrian; Gray and Sharpstone (2, p. 34) consider that it may be Paleozoic; Jackson (13, p. 476) assigns it to the pre-Cambrian; I (5, p. 375), on the basis of radioactive determinations, regard it as pre-Cambrian; Van Doornick[1] thinks that the Katanga metallization, which presumably occurred during the same period as the Rhodesian, was early Paleozoic. Robert[2] reports that Devonian fossils have been found in the Upper Kundelungu, which, however, is many thousand feet stratigraphically above the Mine series. This finding, if correct, would apparently conflict with the deductions based upon the radioactive determinations. The latter have recently been checked[3] by determinations of the atomic weight of lead, giving an age of 640,000,000 years to the Katanga pitchblende. Thus the pre-Cambrian age of the Katanga pitchblende is beyond doubt, and if it is related to the associated granite, that also must be of pre-Cambrian age, and so must the enclosing beds of the Série des mines. Therefore, the host rock of the pitchblende must be pre-Cambrian. If apparent conflict occurs between ages of formations based upon radioactive determinations and those based upon other data, the weight of evidence must rest with the former, because such determinations have been checked and rechecked. Consequently, if the Upper Kundelungu is Devonian, there must be a break between it and the rocks that enclose the radium deposits, and the granites that intrude both series must be of different ages.

Metamorphism

Most of the rocks of the copper belt have undergone metamorphism. The ancient rocks of the basement complex are intensely metamorphosed, in marked contrast to the less metamorphosed Mine series above them.

The copper-bearing beds of the Roan groups all show some metamorphism. The so-called "shales," which contain the ore in the Roan Antelope, N'Kana, and Chambishi mines, have been metamorphosed to hard, compact argillites,

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[1] Van Doornick, N. H., doctorate thesis (in Dutch), The Hague, G. Naeff, 1928; reviewed by E. M. Bunge (in French), Revue de géologie, vol. 10, pp. 126–129, 1929.

[2] Robert, M., Le système du Kundelungu au Katanga: Inst. royal col. belge Bull., vol. 14, no. 2, p. 437, 1933; Recherches lithologiques sur des roches carbonatées du Katanga: Musée du Congo belge Annales, sér. 1, vol. 2, fasc. 1, p. 97, 1932.

[3] Baxter, G. P., and Alter, C. M., Science, vol. 77, p. 431, 1933.

lacking in slaty cleavage and mostly devoid of fissility. These rocks have been variously termed shales, indurated mudstones, hornfels, phyllites, slates, and schists. In places they are schistose (8) or have a phyllitic character (13). Originally sandy or dolomitic shales, they have been recrystallized into dense, fine-grained masses of quartz, sericite, biotite, chlorite, a little epidote and albite, and traces of tourmaline. The feldspathic sandstones have been changed in places to quartzites, which consist of recrystallized quartz and feldspar surrounded by sericite. The dolomites are recrystallized to white or pink masses. In places near granite intrusives contact metamorphism has evidently occurred, with the development of high-temperature silicates.

The metamorphism of the Roan beds is due mostly to load metamorphism incurred at the bottom of synclines under deep burial; in part to dynamic metamorphism, as at Chambishi (8) and N'Changa (13); and in part to the proximity of granite intrusions.

Structure

The sedimentary rocks have been folded into a series of asymmetric anticlines and synclines (fig. 108), whose axes trend generally northwest and plunge in the same direction. The folds are in general simple and open, so that the dips of the limbs are mostly less than 50°; at Roan (figs. 109, 110), N'Changa (fig. 117), and Bwana there are vertical dips and even slight overturning. Some minor cross folds occur (figs. 113–115), and a few major thrust faults and many minor faults have been disclosed.

The sedimentary rocks have been largely cut away from the anticlines, and only the lower parts of the synclines have been left to crop out on the flattish peneplaned surface. The pre-Roan rocks crop out on the sites of the eroded anticlines; the Roan series are preserved in the synclines; and the post-Roan rocks are found only in the centers of the larger synclines. Because of the northwest pitch of the synclines, the Roan ore beds crop out in the form of V's whose open ends diverge northwesterly.

At Roan Antelope (figs. 109, 110), N'Kana, and N'Changa (figs. 116, 117) both limbs and the noses of the synclines are preserved, so that here the ore beds are canoe-shaped. Mufulira (figs. 111, 112) and Chambishi (figs. 113–115) lie on the sides of major synclines.

The intrusions of younger granite appear to have been both contemporaneous with and later than the folding. Davidson's work at Chambishi shows that there the granite was later than the folding (8, p. 139), and I found evidence that granite cuts across minor folds.

Geomorphology

The scanty geologic record presents an incomplete view of the geomorphic development of the region. Subsequent to the deposition and folding of the immense thickness of the rocks of the Katanga system, erosion cut deeply into them before the Lubilash (Triassic) sediments were deposited. Folding had apparently ceased, because the Lubilash rocks are still horizontal. Continued erosion removed all but a remnant of these beds, exposed at the west end of the Katanga copper belt, and cut deeply into the rocks of the Katanga system, leaving only the synclinal remnants referred to. A peneplain, remarkable not only for its flatness but for its preservation, was developed upon the region, truncating folded and horizontal beds and hard and soft rocks alike. Rare monadnocks of hard rocks project as low kopjes above the flattish plain; here and there resistant beds form low ridges.

The making of this peneplain must have involved much geologic time, and it probably stood for a long period at a lower altitude. During this time the water level must have been relatively near the surface and controlled the lower limit of oxidation. There is evidence of a later period of aridity (5, p. 383) during which desert conditions, probably like those of the Kalahari, prevailed. The deep water level indicated by the distribution of oxidation must have been formed during this desert period.

The uplift to the present altitude must have been relatively recent, as the peneplain today is undissected: the present streams have barely notched its surface. They flow across it with disregard of the varied underlying structure. Only a few tributaries are subsequent, and they flow in shallow valleys. The deep etching that follows uplift is yet to be accomplished. The Zambesi River is making such a start in its headward cutting into the peneplain at Victoria Falls. Drainage is not yet well established, swamps are numerous and large, and water covers wide tracts during the rainy season. The region is an undissected uplifted peneplain in an extremely youthful stage of development.

The uplift also probably terminated the arid climate, and during the succeeding epoch of humid climate the water level was raised to its present shallow depth and flooded parts of the copper deposits previously open to oxidation.

Ore deposits

All the Rhodesian sulphide deposits occur in the same rock series, have generally similar ore and similar structure, and are of the same origin. They lie in a strip of country about 70 miles long, parallel to the boundary of Belgian Congo, and constitute the Northern Rhodesia copper belt. With the adjacent Katanga copper belt they constitute a central African metallogenetic province.

There are eight proved commercial deposits—(1) Roan Antelope, (2) Mufulira, (3) Chambishi, (4) Baluba, (5) N'Kana, (6) N'Changa, (7) N'Changa West Extension, and (8) Chingola—and two other deposits not yet proved to be of commercial size. The proved deposits are now grouped into three operating units—the Roan Antelope (1), Rhokana (5–8), and Mufulira (2–4). The first two are established as great low-cost copper producers, and the third is about to be. The other properties are quiescent, owing to depressed economic conditions.

Character

The ore deposits consist of one or more beds of the Lower Roan group that have become metallized with specks of the copper sulphides chalcocite, bornite, and chalcopyrite and traces of other metallic minerals. The gangue consists of the enclosing rock: introduced gangue minerals are negligible. Most of the deposits consist of sulphide ore; some are partly or in places completely oxidized.

The most striking feature of the deposits is a persistent and fairly uniform metallization, over a regular width, for great horizontal distances. The metallized bed is sharply marked off from the nonmetallized hanging-wall and foot-wall beds.

In the disseminated character of the metallization the deposits resemble the "porphyry coppers," but they differ in that they are bedded deposits whose shape is that of the enclosing beds. The deposits all lie within a few hundred meters of the base of the Lower Roan group. Consequently their position is determined by the stratigraphic horizon, and their shape by the character of the folding.

Stratigraphic position

All the commercial deposits lie within the Lower Roan group of the Mine series, the principal horizons of which may be correlated. The Mine series has a total thickness of about 1,500 meters (10, p. 248), and the Lower Roan group of 350 to 600 meters (7, p. 794). The Lower Roan consists of basal conglomerates as much as 200 meters thick, overlain by quartzites, argillaceous beds, feldspathic sandstones, and sandstones with intercalated thin shale and dolomite beds. Toward the top these sediments become finer-grained and more dolomitic and grade upward into the dolomitic beds of the Upper Roan, in which the Katanga copper deposits occur.

The Roan Antelope, N'Kana, and Chambishi deposits are contained in an altered sandy shale bed (argillite) just overlying the basal quartzite; this is also true of part of the N'Changa deposit (7, p. 794), but there ore also occurs in the feldspathic quartzites. At Mufulira the ore occurs at three horizons, principally in feldspathic quartzites just beneath shale or dolomitic beds (7, p. 798). At the N'Changa metallization has occurred at two horizons.

Although the commercial deposits of the Rhodesian copper belt occur in the Lower Roan rocks, noncommercial deposits occur at Lufua, 35 kilometers southeast of Mufulira, near the top of the Upper Roan group, in the same beds that contain the rich Katanga deposits. Also of scientific interest is an occurrence of chalcopyrite near the base of the Kundelungu series in the Mufulira Basin (7, p. 800).

Shape and size

In detail the deposits are tabular in shape, but the tabular masses on a larger scale may be folded or contorted. Their shape in general is now well established save that their bottoms have not yet been determined. They have been proved to be of gigantic size, but knowledge of their ultimate dimensions awaits further development. In view of the great tonnages already developed and the long life established, continued development is not justified. Consequently the maximum dimensions will probably not be known for several decades.

Roan Antelope mine (fig. 108).—The shape and minimum size of the Roan Antelope deposit may be seen in figures 109 and 110. Here the ore bed has been folded into an asymmetric syncline that plunges northwestward. Consequently the ore gains depth from the outcrop at the nose of the syncline to more than 2,000 feet toward the northwest. The position of the cross section A-A' (fig. 110) is shown in figure 109. A similar cross section to the southeast of A-A′ would show great depth. One limb of the syncline is vertical to overturned; the other has a gentle dip; the bottom is keel-shaped, pitching at about 16° NW.

The noteworthy feature of the Roan Antelope deposit is the strike length of the ore. Continuous ore has been disclosed by underground workings or drill holes for 12,000 feet along the north limb and around the nose, and for 16,000 feet along the south limb, giving a proved length of 28,000 feet; a further extension of 22,000 feet is indicated by widely spaced bore holes, making an indicated strike length of about 10 miles. The thickness of the ore bed is 25 to 30 feet.

Mufulira mine.—The Mufulira mine lies on the southwest limb of a major syncline (fig. 108) of which the other limb crops out in the Belgian Congo, 15 kilometers away. The Mufulira limb parallels the Congo border for over 100 kilometers. The deposit, therefore, occupies but an infinitesimal part of the structure and is a simple tabular body with a length of about 7,000 feet along the strike of the beds (fig. 112). The deposit is made up of three lodes (fig. 111), situated one above another and separated by 25 and 45 feet respectively of barren beds. The two lower lodes coalesce toward the northwest to form a single lode over 100 feet thick in places, and they likewise coalesce in depth. The upper lode is not known to connect with the other two in any part of the deposit (12, p. 328). The individual lodes attain 60 feet in thickness, and the total thickness is 70 to 98 feet. They have been cut by bore holes at a vertical depth of more than 3,000 feet, but their lower limit is not known. The deposit has a rake to the east.

Chambishi mine.—The Chambishi mine lies on the north limb of a closed syncline, the center of which is occupied by Kundelungu beds. This deposit is exceptional in that the structure is extremely complicated; the folds are closed, overturned, dragged, and faulted, and the solution of the structure is a noteworthy geologic accomplishment by Davidson (8). The enclosing rocks are more metamorphosed than at the other mines; the ore bed is a sandy calcareous argillite, averaging 75 feet in thickness, the lower part of which is a contorted schist; the metallization was confined to the lower 50 feet of this bed. The average thickness of the ore is about 25 feet, and its proved strike length is over 4,000 feet (8, p. 142). The deepest bore holes have cut rich ore at a vertical depth of 1,200 feet.

The shape of the deposit may be seen from the plan shown in figure 113. The structure is more complicated than is shown on this scale, because a strike length of 2,000 feet has been compressed to 1,200 feet (8, p. 137). Typical cross sections are shown in figures 114 and 115.

N'Kana mine.—The N'Kana mine lies in the center of the Rhodesian copper belt (fig. 108), toward the nose of the same syncline that contains the Chambishi mine. The structure is in general similar to that at the Roan Antelope mine except that the syncline widens rapidly northwestward and the ore occurs on the northeastern limb and does not extend around the nose of the plunging syncline. The main deposit starts approximately 3 miles from the nose and has been followed for a distance of over 8,000 feet along the strike of the beds without reaching the limits. The average thickness is 31 feet (2, pp. 24–26). A break in the metallization intervenes, and another body extends several thousand feet farther southeastward. The greatest vertical depth disclosed to date is 2,663 feet.

In shape, the deposit is also tabular, and in plan and cross section it more nearly resembles that of the Mufulira mine than the others, except that drag folds are present.

N'Changa mine.—The N'Changa mine lies toward the northwest end of the copper belt in a syncline resembling the N'Kana in plan (figs. 116, 117). This syncline, like the Roan, is asymmetric, with one vertical limb, containing the River lode, and one limb inclined 30°, containing the Dambo and New Discovery lodes (fig. 117), which are at different stratigraphic horizons. Farther west, the N'Changa Extension and Chingola deposits are on the same limb. The mineralized beds on the two sides of the syncline are 4,500 feet apart (11, p. 250). The individual ore bodies are tabular in shape.

The River lode has been traced 16,000 feet within the property lines, and the Dambo lode 15,000 feet. Ore has been disclosed to a depth of 2,145 feet.

N'Changa Extension.—The position of the N'Changa Extension deposit may be seen in figure 117. This rich deposit is also tabular in shape and occupies one part of the southeastern limb of the N'Changa syncline. It is an extension of the N'Changa New Discovery lode, and therefore its shape is similar. Its thickness, however, is greater, over 80 feet having been reported. Its strike length is about 8,000 feet.

Baluba deposit.—The Baluba deposit lies on the north side of the Muliashi option of the Roan Antelope (fig. 109) and is an extension of the north limb of the Roan syncline. The deposit is complicated by the intricate structure of several drag folds, and in this respect its shape differs from that of the contiguous Roan Antelope deposit. The strike length is around 2,000 feet, and the thickness is 25 to 30 feet.

Ore reserves and grade

The eventual tonnage of the Rhodesian mines is unknown. Sufficient development work has been done to prove that they are gigantic long-life deposits that justify immediate operation. Consequently, the determination of eventual ore reserves is not of urgent importance and will await future development. The ore tonnages and grades that have been officially announced are shown in the following table:

Ore reserves and grade of Rhodesian deposits

Deposit	Group	Approximate reserves (tons)	Percentage of copper
Roan Antelope	Roan	104,000,000	3.43
N'Kana	Rhokana	127,000,000	4.0
N'Changa	do	95,280,000	3.53
N'Changa Extension	do	46,500,000	6.9
Chingola	do	2,000,000	7.0
Mufulira	Mufulira	116,000,000	4.41
Chambishi	do	25,000,000	3.46
Baluba	do	21,000,000	3.47
		572,780,000	

Surface indications of deposits

These great deposits give few surface indications of their presence. Outcrops are rare. However, most of the large deposits cropped out in at least one place, and this led to their discovery. These croppings had been known and worked in a crude way by natives before the advent of white men.

The determination of the geologic column and the structure made possible the projection of the apices of the lodes to the surface and thus gave locations for exploration by pit and drill. In this way the apices were extended beneath overburden far beyond their croppings. Still other deposits without croppings were discovered by detailed geologic work, which provided locations that were then tested by pitting or drilling.

The surface indications of commercial deposits consist of croppings with or without copper, copper springs, and dambos. The croppings with copper are short exposures of ore beds with malachite, chrysocolla, occasional cuprite or native copper, and rarely a speck of sulphide, and they contain 1 to 4 percent or more of copper. Most of these croppings yield information as to whether the oxidized minerals have formed in place from original sulphide and thus indicate ore beneath, or whether they were transported from some other place and do not indicate the presence of copper beneath.

The croppings without copper may represent parts that either were originally barren or have been leached of their original sulphide content. The two classes can be readily distinguished. The leached outcrops can be recognized with fair accuracy by means of the voids of sulphide derivation, by the presence or absence of indigenous or transported "limonite," and by the nature of the limonite boxworks (5, p. 385).

Copper springs and seeps are found in several of the low-lying areas, from which copper is deposited in oxidized compounds or in the native form. These indicate, of course, that copper is present, but it may have been transported a long distance. Consequently, they are no positive indication of the near presence of ore.

The much referred to "copper dambos," or open stretches in the bush where trees do not grow, were early heralded as indicating outcrops of copper lodes, because such a dambo coincided with part of the Roan Antelope ore cropping near the nose of the syncline. Later work, however, proved that this idea was fallacious (5, p. 386).

Distribution of deposits

All the deposits are restricted to the Lower Roan group of rocks, but no definite cause can yet be advanced to account for the large-scale distribution of the deposit within this group. It is true that the deposits all occur in synclines, but synclines are the only places where the Lower Roan group has escaped erosion. Not all the synclines are metallized, however, and the individual deposits constitute but a small fraction of the synclines in which they occur. Why, for example, should the Mufulira be localized where it is, with many kilometers of nonmetallized ore beds on either side of it? The answer to this question awaits future work. The occurrence may be due to the distribution of intrusive granites.

There appears to be no definite zonal arrangement of the deposits within the main copper belt. All are essentially similar in mineralogy, regardless of their location, even though the individual deposits may portray some distribution pattern.

The ores

Character

The ore consists of specks of sulphides and rare veinlets, rather uniformly disseminated throughout the rock of the ore bed. It is deceptive-looking material. The Roan ore looks like ordinary rock: the copper specks become apparent only upon close inspection. This is likewise true of the ore in altered feldspathic sandstone, although the grain size of the sulphide ore is somewhat larger and it more closely resembles the disseminated ore of the "porphyry coppers."

The individual sulphides occur as discrete shapeless grains irregularly dispersed in the rock. In places they are alined along the bedding planes, as at Roan Antelope. At Chambishi large grains in the schistose rock are oval, with their long axes in the direction of schistosity (8, p. 147). Few sulphide grains are larger than 2 millimeters in diameter; many are as small as 0.0001 millimeter. The size varies with the grain size of the enclosing rock. The Roan sulphides average between 0.1 and 0.3 millimeter; the Mufulira, 0.7 millimeter; the Chambishi, about 1 millimeter. Local sulphide bunches are 5 centimeters in diameter, and a few veinlets an inch or so in width have been noted.

Few sulphides other than copper occur, and the grains are readily separated from their rock matrix, yielding a clean and high-grade concentrate. The specific gravity of the Roan ore is 2.8.

The ore beds as a whole are rather uniformly mineralized over a given length and are sharply delimited against barren walls. Gradational contacts, as in the "porphyry coppers," are practically nonexistent.

In certain places sulphide minerals occur as irregular bunches in small pegmatite dikes and quartz veins at the base of the ore beds.

The Roan, N'Kana, Mufulira, and Chambishi deposits consist almost entirely of sulphide ore. The N'Changa contains mixed sulphide and oxidized ore, and the Extension is largely oxidized ore.

Mineralogy

The mineralogy is simple. There are few sulphides and little introduced gangue.

Gangue minerals.—The gangue consists of the altered host rocks, together with a little quartz, sericite, chlorite, carbonate, and rare tourmaline (5, p. 187).

Oxidized minerals.—The oxidized products that have been recognized in the croppings and in the oxidized or partly oxidized deposits are malachite, azurite, chrysocolla, cuprite, tenorite, native copper, cobalt and manganese wad, goethite, hematite, and jarosite. Cornetite has been found at Bwana M'Kubwa (2, p. 20), libethenite has been mentioned by Gray (2, p. 34), and breberite has been found at N'Changa (11, p. 264). Malachite is the preponderant oxidized copper mineral.

Metallic minerals.—The important metallic minerals are chalcocite, chalcopyrite, and bornite. In addition there are extremely minor amounts or traces of pyrite, linnaeite, covellite, zinc blende, carrollite (?) (11, p. 261), specularite (12, p. 336), and two unidentified minerals, one of which resembles tetrahedrite.

The deposits are conspicuously low in iron, and pyrite is uncommon. It is extremely rare in Roan Antelope and Mufulira, and is most abundant at Chambishi. It is the earliest-formed hypogene sulphide and replaces the rock silicates.

The uncommon sulphide linnaeite (Co_3S_4) is widely distributed in small amounts in the ores of the Rhodesian copper belt and is also a constituent of the Katanga ores. In both regions it is nickel-free. It is sufficiently abundant in the N'Kana mine to give the ore a content of 0.02 to 0.46 percent of cobalt (2, p. 27). It is an early-formed hypogene mineral that clearly replaces the rock silicates and includes blebs of bornite, chalcopyrite, and unreplaced residuals of rock silicates. Some of it is intersected by innumerable veinlets, about 1/25,000 of an inch wide, composed of bornite, chalcopyrite, and chalcocite, singly or together (5, p. 388).

Chalcopyrite is economically the least important of the three dominant sulphides. It is more abundant at Chambishi and N'Kana than at the other mines. It is a hypogene sulphide that has been introduced into the sediments subsequent to their compaction and folding. It has replaced the various rock silicates without discrimination. It is later than pyrite and linnaeite, which it has replaced, but was not observed to have replaced other sulphides. It is earlier than the other sulphides but is in part contemporaneous and intergrown with bornite.

Bornite and chalcocite are the abundant ore minerals. Bornite is less abundant than chalcocite in the shallow workings and more abundant in the deeper ones. It is the predominant sulphide at Chambishi (8, p. 149). Grains and veinlets of the pure mineral cut across, expand into, and replace rock silicates. It has clearly been introduced as an initial deposit by replacement of the enclosing rock, in exactly the same manner as chalcopyrite. It also occurs in association with other sulphides. It is intergrown with chalcopyrite in relations which I interpret as contemporaneous; it cuts and replaces pyrite, linnaeite, and chalcopyrite and is therefore in part later than these minerals. It is not cut by other sulphides save chalcocite. An anomalous bornite has been described elsewhere (5, p. 391).

I interpret the bornite as being clearly hypogene (5, p. 390). The only supergene bornite I observed was in rare microscopic specks formed as temporary transitional stages in the enrichment of chalcopyrite to chalcocite. Gray (12, p. 337) likewise believes it to be hypogene, and Davidson (8, p. 149) presents strong evidence in support of this belief. Jackson states, without proof, that it is supergene at N'Changa and quotes Bancroft as arriving at the same conclusion.

Unusual interest attaches to the Rhodesian chalcocite. Whether it is supergene or hypogene, or both, is a problem of scientific interest and of economic importance. Some diversity of opinion exists in regard to it. It is an abundant constituent of most of the deposits and the sole copper mineral of many parts of the ore beds.

The chalcocite occurs as (*a*) discrete shapeless grains of pure chalcocite; (*b*) veinlets and larger blebs of pure chalcocite; (*c*) varied intergrowths with bornite; (*d*) veinlets in all the earlier sulphides; (*e*) rims surrounding and replacing other sulphide grains; (*f*) ramifying veinlets which follow fractures that traverse other minerals, giving rise to a mesh structure. Chalcocite enclosed within pure calcite was observed at Mufulira. The chalcocite is all orthorhombic.

Grains and veinlets of chalcocite appear to have replaced the rock silicates as an original replacement product. Chalcocite also cuts across and has replaced all the other sulphides except covellite. It was therefore almost the latest sulphide to form.

Microscopically, the chalcocite is observed to occur in many relations to other sulphides. Davidson (8, p. 147) pictures crystals of chalcocite enclosed in chalcopyrite and bornite, which he interprets as hypogene chalcocite. Mutual boundary intergrowths between bornite and chalcocite; subgraphic intergrowths of chalcocite and bornite; octahedral (isometric) intergrowths, with bornite spicules along octahedral partings in chalcocite; lamellar microstructure with triangular (isometric) pseudo-eutectic texture, with microscopic blades of chalcocite in triangular pattern enclosing intergrowths of chalcocite and bornite, pictured and described by me (5, pp. 394–400), are interpreted as indicating contemporaneous deposition of bornite and chalcocite and isometric ancestry of the chalcocite, which must have formed above 91° C. and is therefore hypogene. Rim and mesh patterns of chalcocite against other sulphides, typical of supergene chalcocite enrichment, are pictured and described by me (5, pp. 400–404), by Jackson (11, pp. 268–275), and by Gray (12, pp. 337–341).

Diverse views regarding the hypogene or supergene origin of the chalcocite are held by different investigators. Jackson and Bancroft (11, pp. 268–275) think that all the chalcocite and all the bornite are supergene; Schneiderhöhn (9) states that the chalcocite is all hypogene; Sharpstone (6, p. 15) thinks it is mostly hypogene; Davidson (8, p. 147) and I (5, pp. 400–404) think that a considerable but unknown part of it is hypogene but recognize also clear evidence of supergene chalcocite; and Gray thinks that it is predominantly supergene but recognizes some hypogene chalcocite (12, p. 339).

Of the other sulphides, covellite is a rarity and is supergene (5, p. 391); carrollite, reported from N'Changa (11, p. 261), is of doubtful determination; sphalerite is rare and is reported from Chambishi (8, p. 150) and Mufulira (12, p. 335; 5, p. 392); specularite is reported from Mufulira (12, p. 336).

Paragenesis of ore minerals.—The general paragenesis of the ore minerals, except for chalcocite, is fairly well agreed upon by different investigators. Pyrite and linnaeite were formed first; the position of sphalerite is unknown, but at Mufulira it is placed by Davidson after chalcopyrite; next came chalcopyrite, then chalcopyrite and bornite, bornite, bornite and hypogene chalcocite, hypogene chalcocite, supergene chalcocite, covellite, and oxidation products. Jackson and Bancroft alone place bornite among the later or supergene minerals, and Jackson and Gray place all the chalcocite later than bornite. Davidson, Schneiderhöhn, Sharpstone, and I regard part of the chalcocite as contemporaneous with bornite. Such overlapping of deposition is common among copper sulphides. The sequence of deposition, then, is in general a diminishing one with respect to iron and sulphur.

Distribution of the minerals.—There appears to be no common systematic arrangement of minerals within the included deposits. At the N'Kana mine chalcopyrite is reported to be most abundant in the deepest workings. In general, bornite and chalcopyrite are more abundant at depth than in the shallower workings, and chalcocite is less abundant at depth. At Chambishi the deepest ore consists almost entirely of bornite and chalcopyrite. At the Roan Antelope mineral maps compiled by Sharpstone show a progressive change horizontally from dominant chalcocite at the east end to bornite and chalcocite farther west. There is also a suggestion that chalcopyrite is proportionately greater in amount near places where granite intrudes the ore beds. The distribution of chalcocite in general shows no definite relation to the surface. At the Mufulira mine, however, Gray has shown a definite relation between the chalcocite and the surface (fig. 118), with chalcocite dominant above and decreasing with depth.

Oxidation and enrichment

Weathering

In this flattish region weathering has been more rapid than soil removal by erosion. The result is a thick regolith of reddish soil, laterite, and subsoil, typical of well-watered tropical regions. Consequently, rock outcrops are few, and much of the areal geology had to be determined by sinking pits to bedrock, or from bore holes. The products and depth of weathering vary according to the underlying rocks. The depth of soil ranges from 1 to 5 feet; in places the soil is underlain by lateritic formations as much as 6 feet thick, composed of "limonite," hematite, and residual quartz, beneath which is subsoil as much as 20 feet thick, which in turn merges into thoroughly weathered rock. Weathering is deepest in the dolomites, feldspathic sediments, and gabbro and may reach 300 feet; 100 feet is common; with quartzite and granite it averages around 20 feet; with argillaceous rocks 100 feet or less. In places of inclined beds the drill may pass through fresh rock into underlying beds of thoroughly decomposed rock.

Oxidation

Oxidation of all the deposits is universal above the water table, which ranges from the surface to 200 feet. In addition, there is considerable deep, erratic oxidation. The upper oxidation has yielded two types of oxidized zones—one in which the copper has been leached, leaving a barren cropping or gossan, and one in which there has been complete or nearly complete transformation of sulphides in place to oxidized copper compounds, yielding an oxidized ore only slightly less in grade than that of the underlying sulphide ore. In places the two types intermingle, particularly near the surface.

The croppings of the first type may be so completely leached that no trace of visible copper remains. Only the voids vacated by sulphides, a trace of iron oxide stain, and "limonite" boxworks in the cavities attest the former presence of sulphides. This type can be recognized only after careful examination with a powerful hand lens. More commonly, however, a little residual malachite or chrysocolla indicates that copper was once present. Part of the Mufulira, N'Kana, and

Roan Antelope outcrops are of this type, but parts of each contain more abundant oxidized copper compounds that were sufficiently noticeable to lead to their discovery. At the Roan Antelope oxidation is complete down to 100 feet, and a considerable proportion is oxidized down to 200 feet. Similar conditions prevail at Mufulira.

Chambishi for the most part is representative of the second type. Barren lode outcrop is rare: most of the outcrop contains 2 to 3 percent of copper in the form of malachite, so finely disseminated in places that it cannot be seen by the naked eye. The transformation from sulphide has occurred mostly in place, and leaching of copper from the oxide zone is only partial. Davidson states (8, p. 142) that "at or near the surface it averages 1 percent lower than the primary ore." Here the water level is at a depth of 40 to 50 feet; oxidation is complete to 100 feet and predominates to 300 feet (8, p. 144). At N'Changa and N'Changa Extension oxidation is "nearly complete from the surface to depths of 200 or 300 feet, the upper 100 feet being, in addition, usually thoroughly leached" (11, p. 256). At the old Bwana M'Kubwa mine complete oxidation has occurred. The oxidized copper minerals occupy the sites of former sulphides, and there has been little copper migration.

The erratic oxidation deep beneath the water table presents an interesting problem. It has been noted that complete oxidation occurs beneath the water table at Chambishi, N'Changa, and N'Changa Extension. At the Extension mine most of the total copper at all depths is in oxidized form; at N'Changa over half of the total copper is oxidized. In the other mines only a very small proportion of the total copper is oxidized, and this is fitfully distributed in the midst of or underlying sulphide ore. Many bore holes have passed through sulphide into underlying oxidized ore and again into sulphide. An extreme case of this occurred at Mufulira, where a drill hole after passing through fresh rock struck an oxidized bed at a depth of 2,000 feet.

Such deep oxidation occurs in the more permeable beds. At Mufulira it is deepest on the hanging wall of the upper ore body and on the footwall of the lower body. This erratic distribution of oxidation is apparently due to structural control. In inclined beds of varying permeability oxidizing waters moved down the dip of the more permeable beds; if these happened to lie at the base of the ore deposit, then deep oxidation of the sulphides in the lower ore beds could take place, while overlying metallized beds might escape oxidation. Thus local pockets of oxidation may occur at the base or in the middle of sulphide beds.

Such oxidation so many hundreds of feet beneath the present water table requires special explanation. It cannot have taken place beneath the water table, where ferrous salts prevail. The idea of a deep artesian circulation carrying oxygenated waters downward is eliminated, because of the topography (5, p. 382). The deep oxidation must indicate an earlier period of low water level which permitted deep penetration of surface oxidizing waters. Such conditions probably prevailed during the period of arid climate that preceded the present one (5, p. 383).

The oxidation yielded malachite as the most abundant oxidized copper mineral; chrysocolla is common, native copper is widely present, and azurite and cuprite are rare.

Supergene sulphide enrichment

Considerable interest is attached to the question of the occurrence and extent of enrichment because of the abundance of chalcocite, a universal secondary copper sulphide. Its presence alone might be considered by some a presumptive evidence of enrichment, but as chalcocite may be of either supergene or hypogene origin, other evidence is necessary.

Conclusive microscopic evidence of supergene enrichment by chalcocite has been given by Bancroft (2), Davidson (8), Jackson (11), Gray (12), and me (5). This secondary chalcocite, some of it sooty, has replaced earlier sulphides around the rims of grains and along intersecting fractures. It yields microtextures typical of supergene sulphide enrichment. Traces of covellite have also been deposited during supergene enrichment. Jackson and Bancroft also consider that all of the bornite is due to supergene enrichment, an opinion that is not concurred in by the other investigators. Gray's diagram (fig. 108) shows a relation of dominant chalcocite to the surface—a condition strongly suggestive of supergene enrichment.

Certain field conditions are favorable for supergene enrichment: oxidation has taken place; sulphides have been broken down in the oxidized zone; meteoric waters are present and proper climatic conditions exist; the ore beds are permeable; and sulphides to act as precipitants exist below the oxidized zone. In part, the mineral distribution suggests it.

However, there are other conditions not so favorable for extensive and thorough supergene enrichment. This process requires, among other things, the presence in fair abundance of pyrite and chalcopyrite, which on oxidation yield ferric sulphate to dissolve the copper. But pyrite is almost lacking in the Rhodesian copper belt, and chalcopyrite is subordinate. Also, the carbonate present in the rocks is unfavorable for extensive enrichment, because it reacts readily with copper sulphate to form copper carbonates, and the neutralizing effect of the feldspathic rocks is rather high. In addition, the extensive fixation of copper in oxidized form has prevented its downward migration to form supergene sulphides. These conditions are less prominent at Mufulira than at Roan Antelope. Hence, greater supergene enrichment would be expected at Mufulira. Supergene sulphide enrichment, therefore, may not be so extensive as the mere distribution of chalcocite alone might imply.

Part of the chalcocite is believed by Davidson and me to be hypogene; Sharpstone and Schneiderhöhn think that all or nearly all of it is hypogene; Gray recognizes some hypogene chalcocite (12, p. 339) but thinks that most of it is supergene. Such hypogene chalcocite has not resulted from supergene enrichment. Consequently, the extent of supergene enrichment depends upon what proportion of the chalcocite may be hypogene and what supergene, and on this point there is divergence of opinion. Bancroft and Jackson, believing all of the chalcocite and bornite to be supergene, think that enrichment has been extensive and deep and accounts for the deepest chalcocite found. Gray considers that at Mufulira nearly all of the chalcocite is to be accounted for by enrichment, which extended to more than 600 meters in depth. I believe that enrichment has clearly occurred but was not nearly so extensive as the distribution of the chalcocite, a considerable part of which must be regarded as hypogene.

Regardless of the extent of sulphide enrichment, or whether there is much, little, or no hypogene chalcocite, it is clear that the commercial grade of the Rhodesian ores is not dependent upon enrichment. The primary mineralization itself consisted chiefly of the deposition of copper sulphides in sufficient abundance to constitute an ore of excellent grade, which has in part been increased by supergene processes. Even after the parts of the deposits enriched by supergene processes have been extracted, the Rhodesian copper belt will long continue to be a great copper producer. In this respect these deposits differ from most of the American "porphyry coppers."

Origin of the ore deposits

The remarkable distribution of these ores for great distances along thin sedimentary beds early led to the suggestion of a syngenetic origin for them. This suggestion, however, was quickly discarded by all those who carried on field work in the area, but has been advanced by Schneiderhöhn (9). Field and microscopic study indicate clearly that the ores are epigenetic. They were introduced subsequent to the formation of the host rocks and even later than the folding of the beds. Stringers and veinlets of sulphides cut across the folds at Roan Antelope and N'Kana, and individual sulphide grains intersect and replace rock minerals that are alined by original deposition or by metamorphism. Jackson (11, p. 267) concluded likewise that the metallization was later than the metamorphism of the ore beds. In a larger way also, Davidson (8) has shown that at Chambishi the localization of the ore is dependent upon the folding. There is nothing to indicate and much to oppose the possibility that syngenetic sulphides were later reconcentrated into their present positions.

The sulphides have been deposited by replacement of the rock silicates and cementing substances. They cut across, eat into, and enclose residual nuclei of the rock minerals; they occur in threads that traverse several adjacent host minerals and have enlarged themselves at the expense of the silicates. Their outlines preclude the possibility that they have occupied cavities not of their own making. They are accompanied in places by introduced quartz, sericite, carbonate, chlorite, and rare tourmaline. The ore and gangue minerals and the accompanying alteration products are characteristic of deposits formed by hydrothermal solutions.

Considerable evidence exists to suggest that the metals and the hot waters were hydrothermal phases of the younger granite intrusions. The ore and introduced gangue minerals are clearly of the type formed from hot waters of igneous derivation. The minor contact metamorphism with typical copper minerals, adjacent to the intrusive granite at Muliashi; the proximity of ore to the granite; the occurrence of copper and cobalt sulphides with quartz and pegmatitic veins that are associated with the granite; and the occurrence of copper sulphides with fluorite, and other evidence noted by Jackson (11), all point to a genetic association with the younger granite.

The localization of the ores in certain parts of the belt, particularly along certain restricted beds, is puzzling. The restriction to certain parts of the belt is apparently due to the proximity of granite intrusions and in part to local minor or drag folds. The localization within single beds is probably a result of greater relative permeability of the ore beds than of the overlying and underlying beds. Gray thinks that at Mufulira the overlying beds acted as an impervious dam to the ascending metallizing solutions and caused them to migrate laterally along the ore beds (12, p. 336).

In summation, the Rhodesian copper deposits may be considered to have been formed by disseminated replacement of certain favorable sedimentary beds, by means of hydrothermal solutions that were one phase of the igneous activity that gave rise to the younger granites. These solutions rose from the magma chamber along fractures to nearby parts of favorable permeable beds, along which they spread; or, where cupolas of granitic magma projected directly into the favorable beds, the metallizing solutions streamed out of the cupolas along the permeable beds in the direction of least pressure until precipitation took place. The metallizing solutions were poor in iron and sulphur; the earlier emanations were richer in these elements than the later ones, and consequently there was a progressive decrease in the iron and sulphur content of the later hypogene minerals, ending with the iron-free, high-copper sulphide, hypogene chalcocite.

After long-continued erosion the deposits were exposed at the surface, allowing oxidation and enrichment to take place. This occurred in a period of arid climate preceding the present one, when the water table was low and oxidation penetrated deeply. With the subsequent humid climate, the water table was raised, the previous deep oxidized material became flooded, and further oxidation was restricted to the shallow zone above the present water table—the condition in which the deposits occur today.

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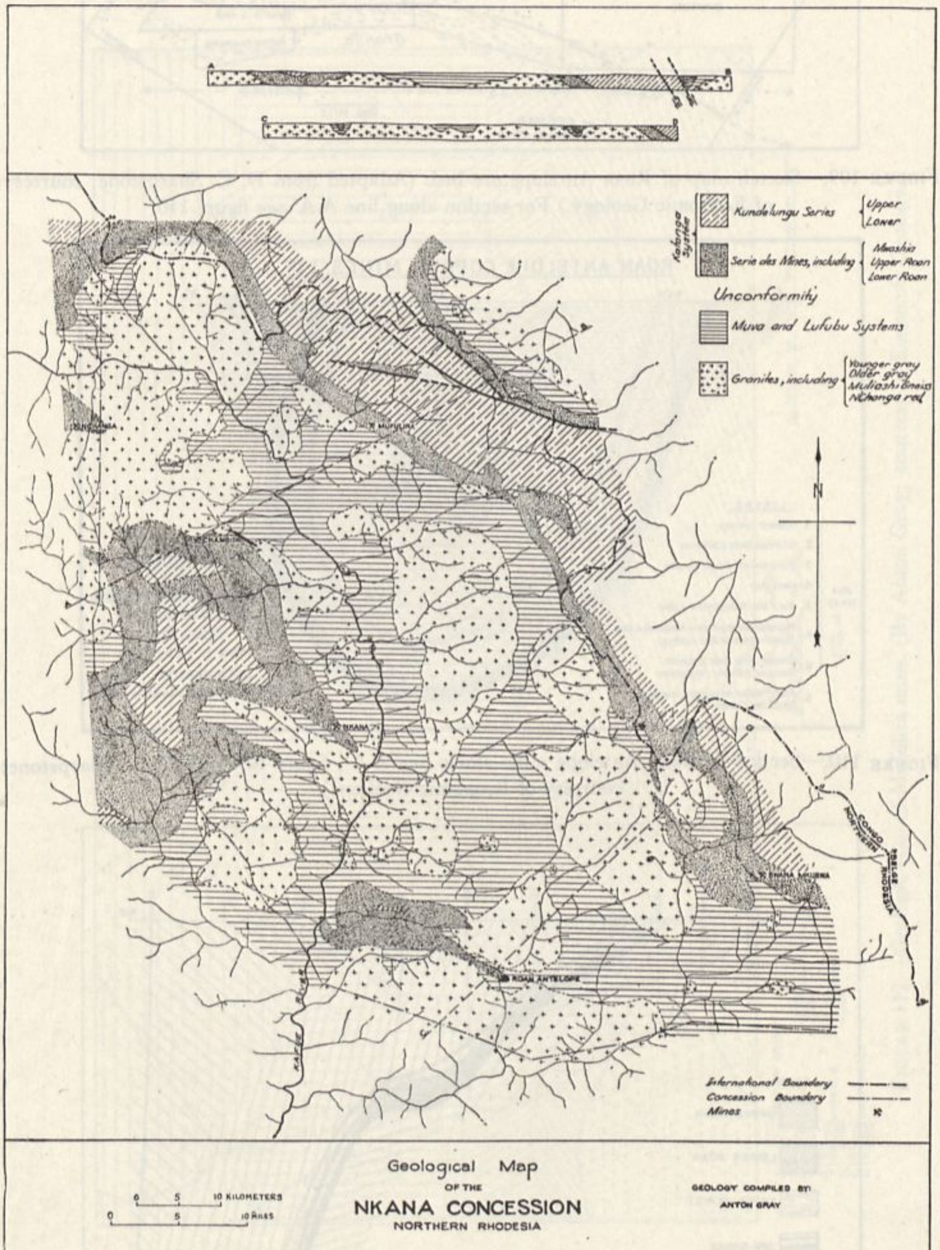

FIGURE 108.—Geologic map of the N'Kana concession, Northern Rhodesia. (From D. M. Davidson; courtesy of Economic Geology.)

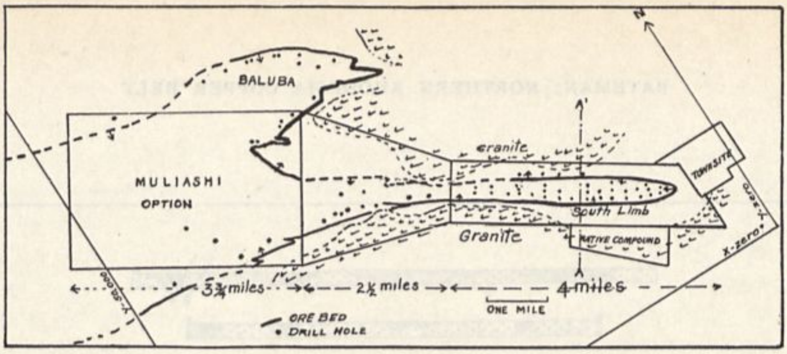

FIGURE 109.—Sketch map of Roan Antelope ore bed. (Adapted from D. C. Sharpstone; courtesy of Economic Geology.) For section along line A-A′ see figure 110.

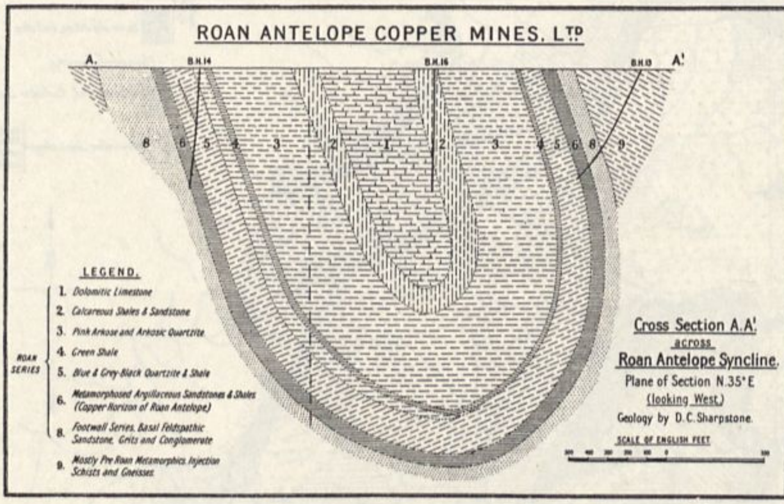

FIGURE 110.—Section in Roan Antelope mine along line A-A′, figure 109. (By D. C. Sharpstone; courtesy of Economic Geology.)

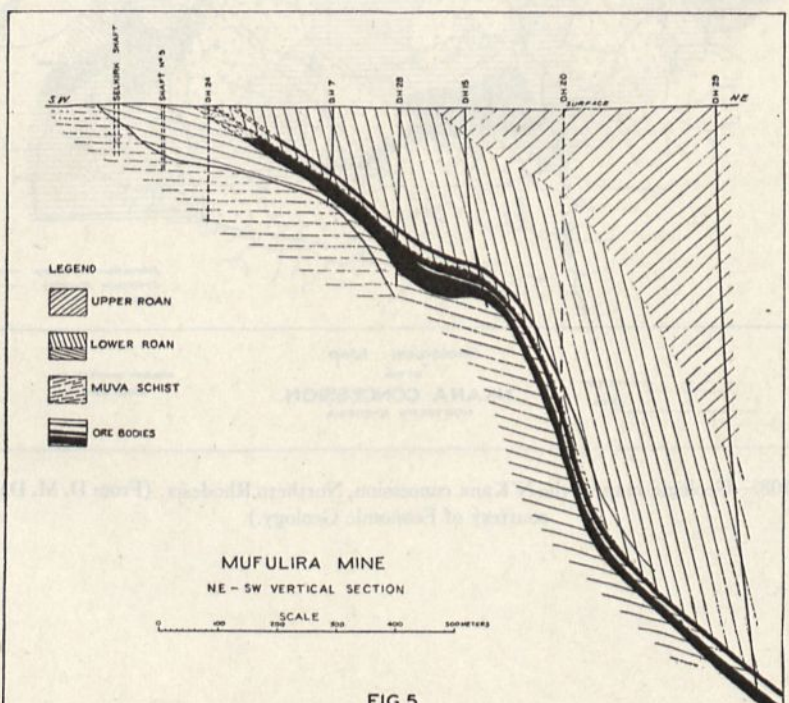

FIGURE 111.—Vertical northeast-southwest section in Mufulira mine. (By Anton Gray; courtesy of Economic Geology.)

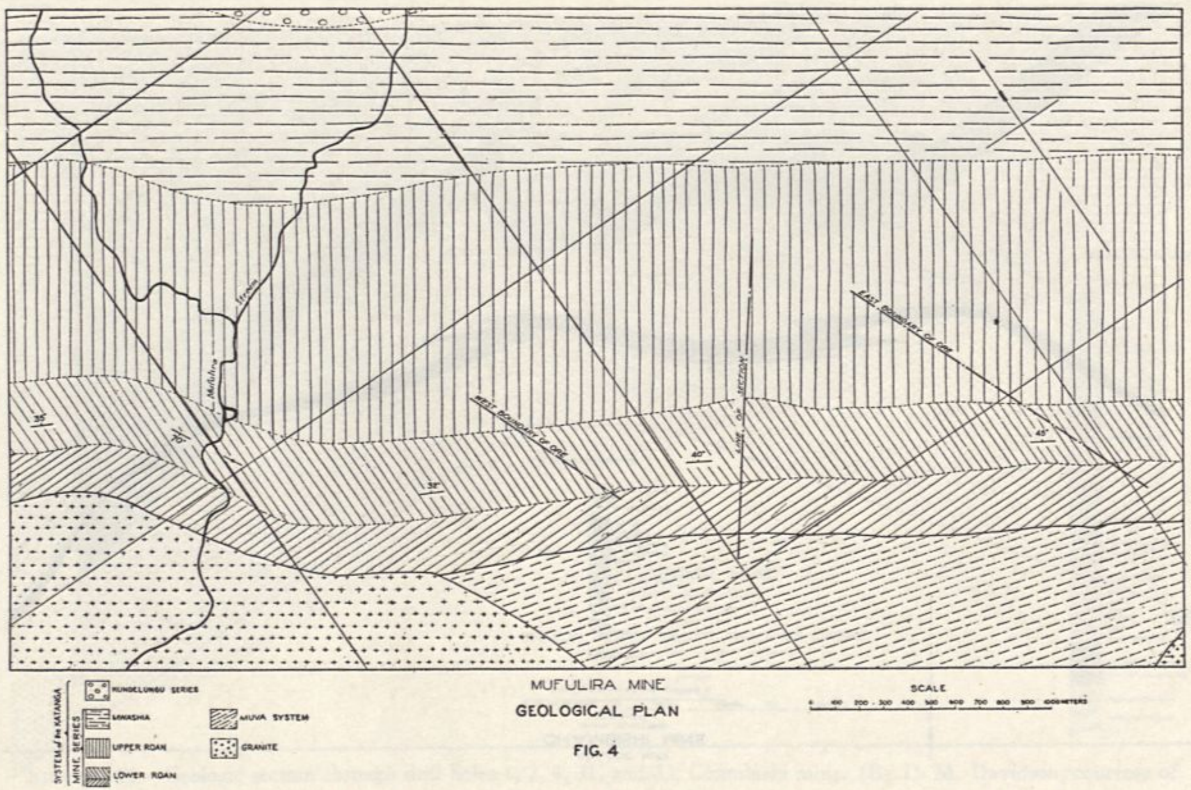

Figure 112.—Geologic plan of Mufulira mine. (By Anton Gray; courtesy of Economic Geology.)

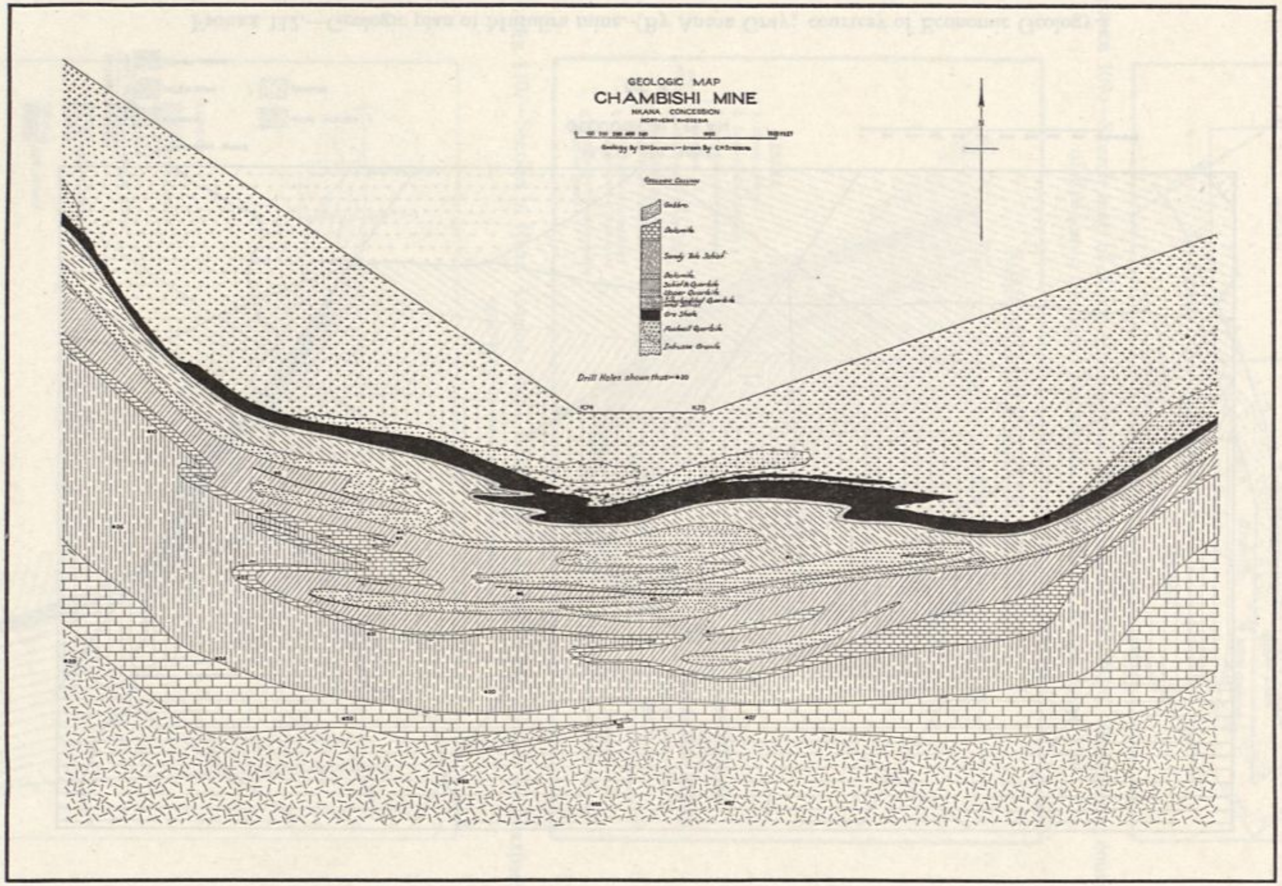

FIGURE 113.—Geologic map of Chambishi mine, N'Kana concession. (By D. M. Davidson; courtesy of Economic Geology.)

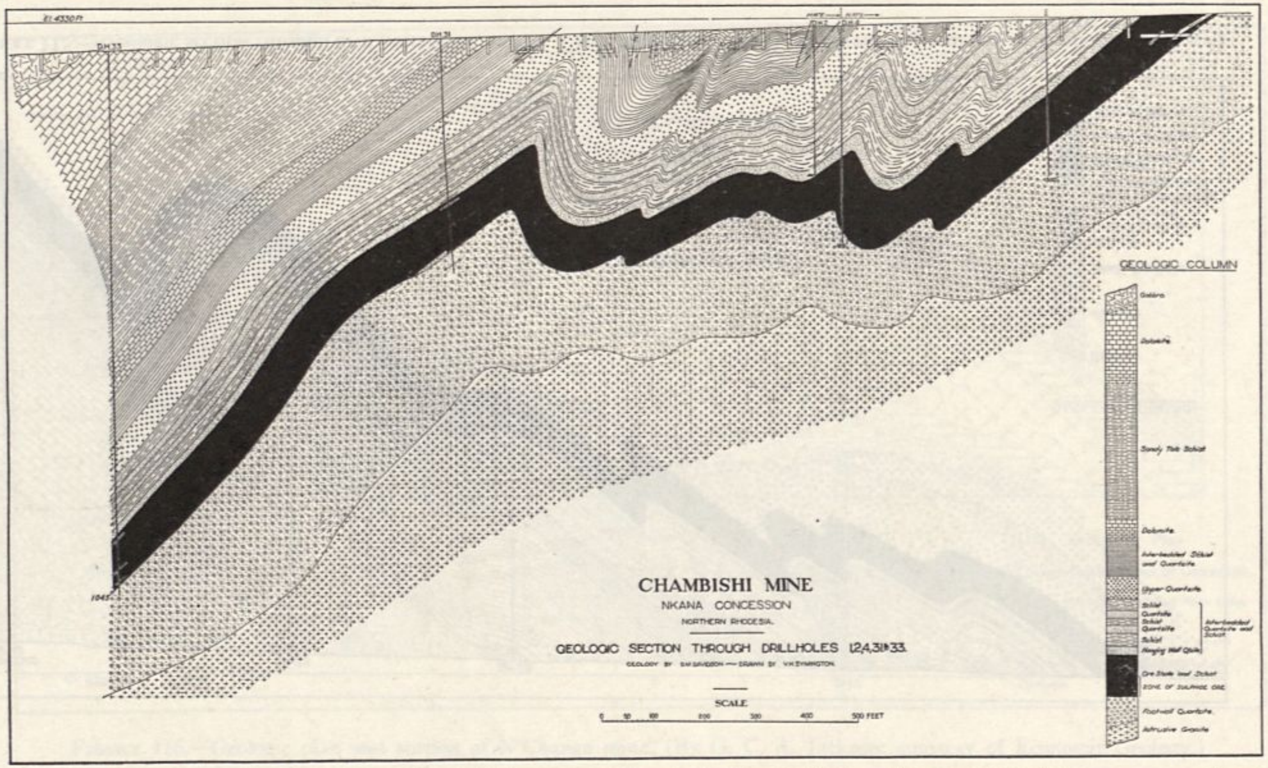

FIGURE 114.—Geologic section through drill holes 1, 2, 4, 31, and 33, Chambishi mine. (By D. M. Davidson; courtesy of Economic Geology.)

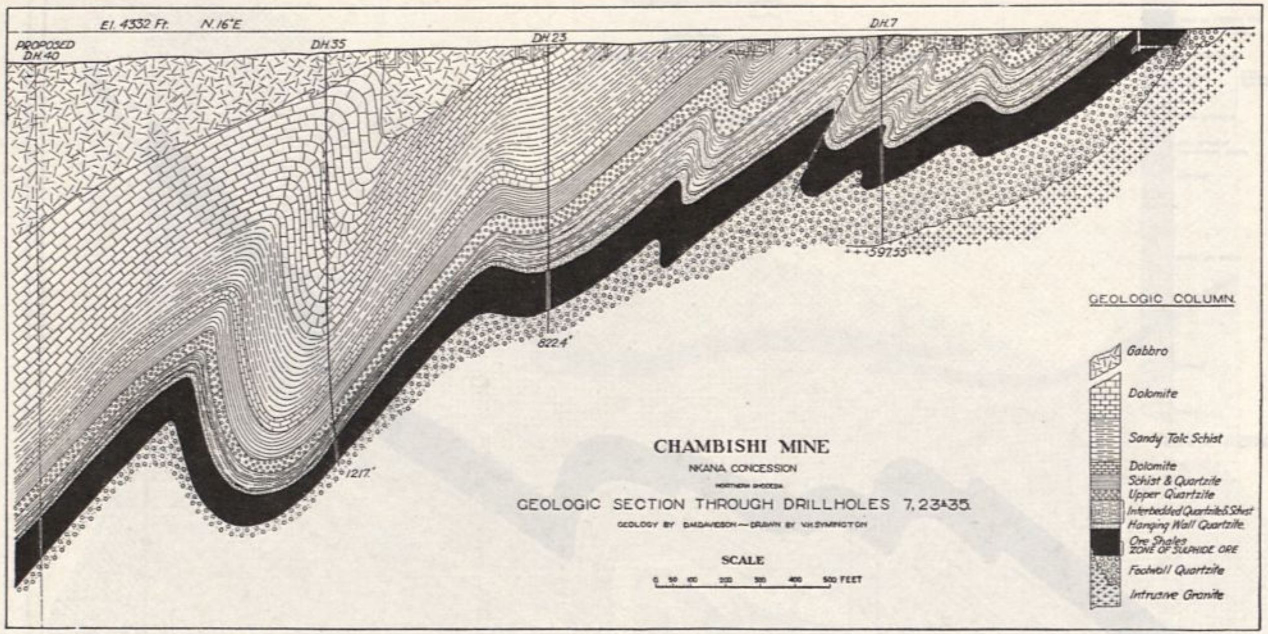

FIGURE 115.—Geologic section through drill holes 7, 23, and 35, Chambishi mine. (By D. M. Davidson; courtesy of Economic Geology.)

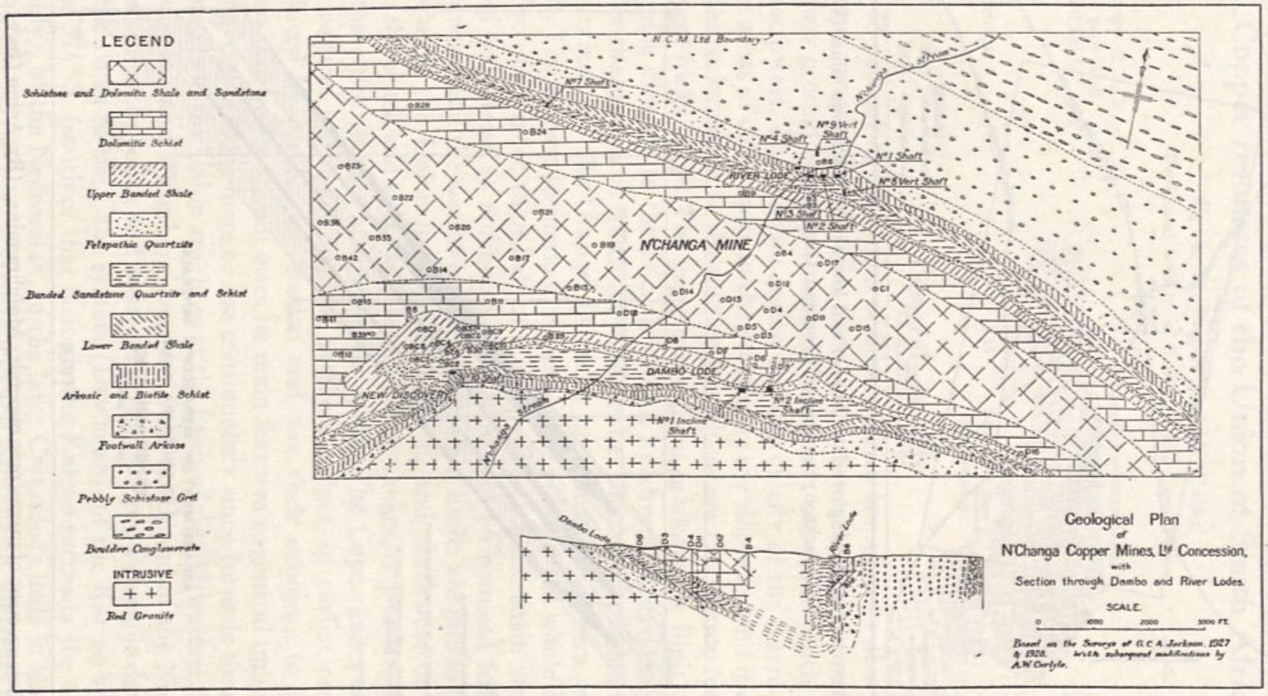

FIGURE 116.—Geologic plan and section of N'Changa mine. (By G. C. A. Jackson; courtesy of Economic Geology.)

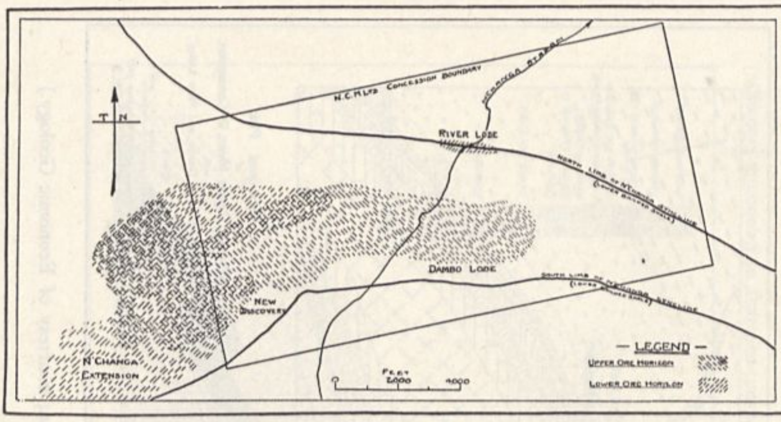

Figure 117.—Sketch plan showing overlap of upper and lower beds, N'Changa mine. (By G. C. A. Jackson; courtesy of Economic Geology.)

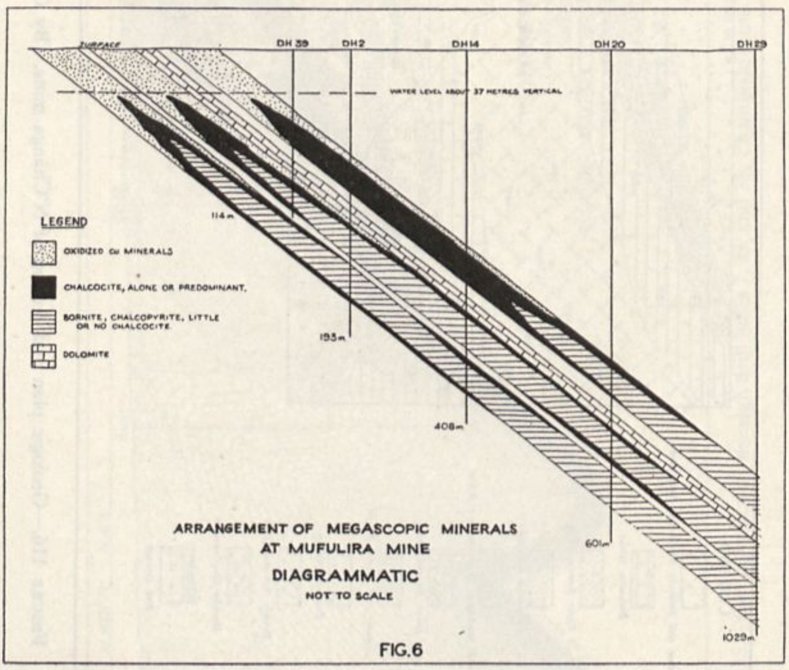

Figure 118.—Arrangement of megascopic minerals, Mufulira mine. (By Anton Gray; courtesy of Economic Geology.)

Copper resources of the Union of South Africa

By A. W. Rogers and M. Weber[1]

Geological Society of South Africa, Cape Town

General geology

About 38 percent of the Union of South Africa is a plateau above the 4,000-foot contour stretching 800 miles from southwest to northeast, with a narrow belt of lower ground between it and the southeast coast and much wider tracts on the northwest. The plateau region consists chiefly of the Karroo formation, with large areas of older rocks in the northeast; the slopes around it are made up of the older rocks except in the east and south, where the Karroo formation and still younger rocks occur. The great escarpment marking the limit of erosion of streams going directly to the coast is capped by strong formations with low inward dip or the granite on which they used to lie. The country behind the escarpment is drained by the Orange, Olifants, and Limpopo Rivers, which break through it. The Karroo formation probably once covered the whole of the Union and still occupies more than half of it as a wide tectonic basin stretching 800 miles from southwest to northeast, with a belt of pronounced folding of late Karroo date around the southwest end; its present limits are due to erosion. The oldest rocks in the Union lie northeast, north, and northwest of the Karroo region; to the south and southwest are the Cape ranges, due to late Karroo folding, together with smaller areas of older rocks. The Cape ranges are the chief orogenic features in the Union; the northern ranges, of earlier orogeny, were much reduced by pre-Karroo erosion and owe their exposure to post-Karroo denudation. The subcontinent owes its main features to general upheaval, which seems to have affected it more or less continuously since Jurassic time. The great unconformities in the Union are those at the bases of the Witwatersrand-Ventersdorp, Transvaal, and Waterberg systems in the north and of the Nama (Transvaal?) system in the south and west, all perhaps of pre-Paleozoic date; later are those at the bases of the Cape system (Devonian), of the Karroo system north of latitude 31½° S. (south of that latitude the Karroo succeeds the Cape system conformably), of the Neocomian, of the later Cretaceous beds in the south and east, and of the Tertiary beds. Neocomian and later marine deposits are confined to coastal regions, but the terrestrial deposits of the Kalahari region perhaps date back to Upper Cretaceous time.

[1] The account of the Messina mine was written by Mr. Weber. The remainder of this paper was written by Mr. Rogers.

Metallogenic provinces

Discussion of the metallogenic regions is hindered by difficulties of correlation—for example, of the Bushveld igneous complex with certain intrusions in the south and northwest of the Cape province—as well as by uncertainty of the age limits of mineral deposits—for example, the copper lodes of Messina and those of unproved value farther east, in the Limpopo Valley. The order in which the several "provinces" are named in the following list is not meant to imply proved chronologic sequence in deposition of ores, though in some respects the relative age is not in doubt—as, for instance, the earlier date of the Bushveld complex ores than of those associated with the Karroo dolerites.

Metallogenic provinces of the Union of South Africa

Swaziland (Archean)	Barberton and Murchison Range (Au, Sb, As, Be).
	Swaziland and Zululand (Au, Sn).
	Namaqualand (Cu, Ta, Be, Bi).
	Prieska-Kenhardt (Wo, Cu).
	Madibi (Au).
Witwatersrand-Black Reef (pre-Cambrian)	Witwatersrand (Au) (syngenetic sedimentary).
Transvaal-Nama (pre-Cambrian)	Central Transvaal Bushveld (Pt, Ni, Sn, Wo, Mo, As, Au, Cr, F).
	Kaap Plateau (Pb, Cu, Fe) (syngenetic sedimentary).
	Buffelspoort (Fe) (syngenetic sedimentary).
	Pilgrims Rest (Au).
	Palabora (Cu).
	Cape (Sn).
Post-Waterberg (late pre-Cambrian?)	Zoutpansberg (Cu).
	Postmasburg (Mn).
Karroo (Carboniferous-Jurassic)	Transkei-Natal (Cu, Ni, Pt in differentiates of doleritic magma; Fe, syngenetic sedimentary).
	Bushveld (Pt in quartz veins).

Namaqualand field

The copper mines of Namaqualand are in igneous rocks intrusive in granitic gneiss and highly metamorphosed sediments forming layers in the gneiss. Though the outcrops were first examined by Europeans in 1685, serious work on them did not begin until 1852, since when more than £20,000,000 worth of copper has been produced there. At first high-grade ore only was exported, then local smelting with Welsh coke produced a regulus of about 50 percent, which was exported for many years as the chief product of the field. Fines were treated by sintering or briquetting, and some copper was obtained by leaching. In later years a flotation process (Elmore plant) was used at Concordia. The intrusions form dikes and other bodies of small size; 344 of these are known, distributed over more than 1,000 square miles; copper has been produced from about a dozen of them, but only half that number can be reckoned as successful mines. The limit of workability in 1913 was about 4 percent of metallic copper. The region is arid (average annual rainfall 5 inches), and the green copper salts due to weathering make many outcrops conspicuous, even where the rock contains too little copper to be worked. The distribution of the outcrops in the country near Concordia, where they are abundant, is illustrated by figure 119. The country rock is gneiss with

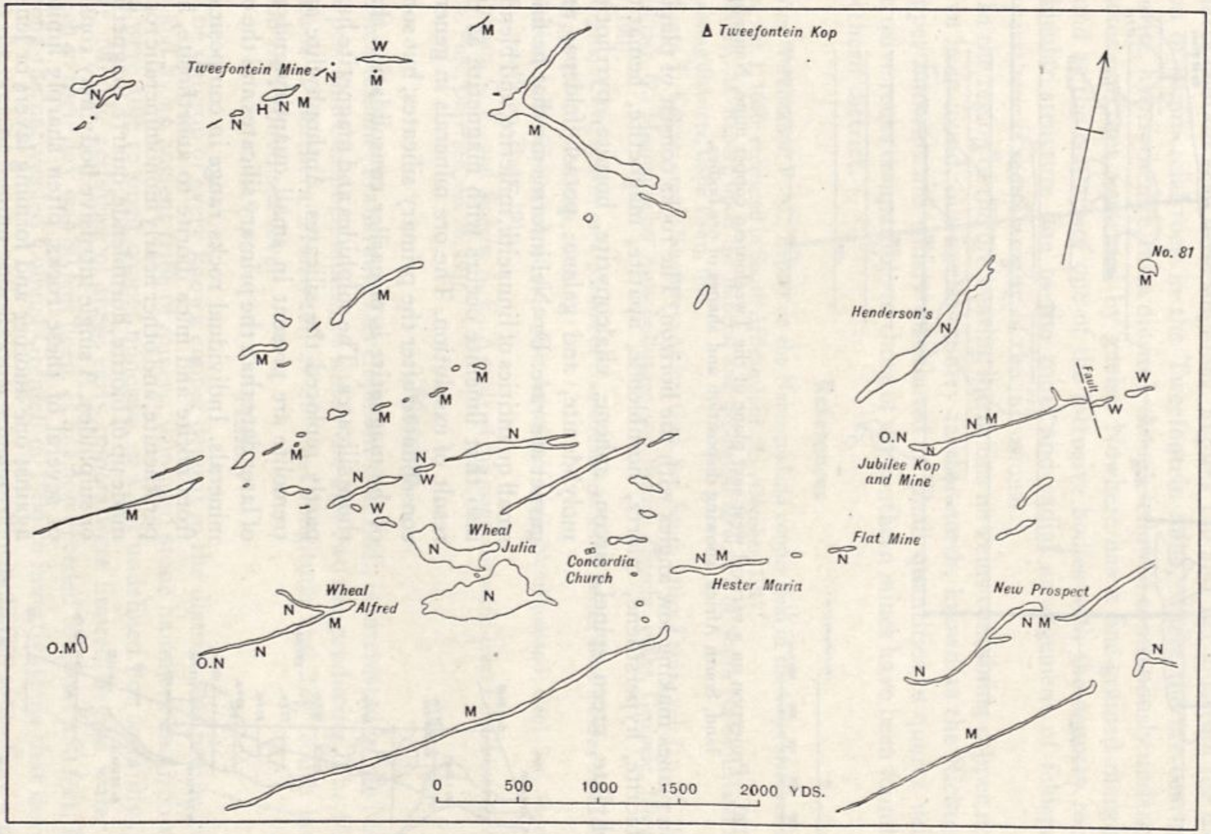

FIGURE 119.—Plan of outcrops of ore-bearing rock near Concordia, Namaqualand, South Africa. H, Hypersthenite; N, norite; M, mica diorite; W, plagioclase rock; O. N, orbicular norite; O. M, orbicular mica diorite. The intrusions are lettered according to the dominant type of rock in them.

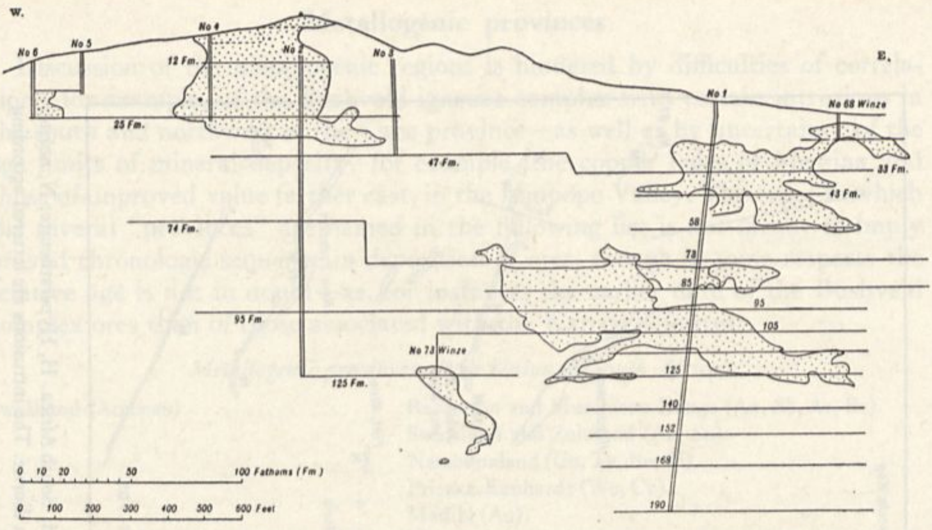

FIGURE 120.—Projection on a vertical west-east plane of the Tweefontein copper mine, Namaqualand, South Africa, showing disposition and shapes of ore bodies.

foliation planes making low angles with the horizon. The rocks consist of plagioclase, biotite, hypersthene, quartz, hornblende, apatite, magnetite, hematite, anthophyllite, green spinel, zircon, sphene, chalcopyrite, bornite, pyrrhotite, molybdenite, and galena; potash feldspar and garnet are rare. Dr. Nel informs me that he finds small quantities of linnaeite, millerite, and blende, also that ilmenite occurs with magnetite as the result of exsolution. The ore minerals in general consolidated after the primary silicates, but some of the magnetite is of earlier consolidation than those silicates. The sulphides and magnetite have partly replaced the silicates. Anthophyllite and tremolite are present in small quantity and are of later date than the primary silicates and the ore minerals. Individual rocks range in composition from norite and mica diorite to anorthosite, hypersthenite, and other nearly monomineralic rocks made up of biotite, hornblende, quartz, magnetite, or sulphides. A single intrusive body may consist of several of these rocks, often sharply limited against one another and forming layers or lenses parallel to the walls of the intrusion in narrow bodies, but of irregular shape in the wider bodies. In the mines worked in 1913 (Ookiep, Nababeep, Narrap, Tweefontein) the profitable ore at each mine was almost entirely in one of the two or more varieties of rock exposed in the mines—in the mica

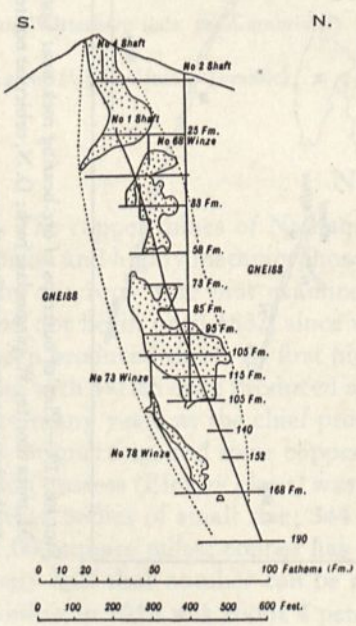

FIGURE 121.—Projection on a vertical north-south plane of the Tweefontein copper mine, Namaqualand, South Africa.

diorite at Ookiep, hypersthenite at Nababeep, and norite at Tweefontein. The anorthosite and those rocks made up almost entirely of hornblende, biotite, or quartz contain very little sulphides. Figures 120 and 121 illustrate the distribution of commercial rock in the Tweefontein mine, where the ore-bearing dike (norite, hypersthenite, mica diorite), though followed continuously underground, makes outcrops separated by gneiss. Nowhere has a fine-grained margin been found at the contact of one of the intrusive bodies with the country rock, but orbicular structure due to the zonal and radial arrangement of feldspar and hypersthene is seen in many of the intrusions.

In the region of the ore-bearing intrusions no veins containing copper minerals have been found, but in the country farther north, known as the Richtersveld, copper minerals are widely distributed in small quantities in quartz veins; no intrusive rocks comparable to those of the southern mines have been found in the northern district.

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Messina

The Messina (Transvaal) Development Co., Ltd., is interested in the Messina, Harper, and Campbell mines, of which the first two are producing. The Messina mine is in northern Transvaal, at 30° east longitude and 22½° south latitude, 2,000 feet above sea level.

History

The outcrop of every known copper deposit in the district was prospected and worked by an ancient tribe of miners, who used stone hammers and iron wedges and were able to smelt copper minerals, in a yet undefined but certainly distant past. Mining activities of these early miners were limited by the water table, which in their day was 80 feet deep. It has now receded to about 150 feet. Rumor among the natives led Colonel Grenfell in 1906 to investigations that developed into the present mining undertaking, which produces 33,000 tons of ore a month.

Geology

The country rock is a banded, much differentiated, partly gneissose hornblende granite. A line of weakness, known for over 20 miles and intensely prospected by the ancients, traverses the banded granite in a northeasterly direction, producing long, straight, clean-walled fissures.

A dolerite dike, which in parts is hardly altered, filled the main fissure, which was torn open again by later adjustments. After the consolidation of the dike disturbances set in, producing shorter (1,000 feet) fractures and fracture breccias along and near to the line of weakness and the dike, which they cross at acute angles (20° and 30°) and in places fault. During the formation of these fractures, ascending mineralizing solutions were forced under enormous pressure into the openings, altering the country rock to a distance of hundreds of feet away from the channels, to silicified zoisite-quartz aggregates, which contain hardly any copper minerals. In and along the channelways new minerals were formed in the following sequence: Prehnite, delessite, specularite, quartz; secondary feldspar, quartz; quartz, chalcocite, bornite, chalcopyrite; and as a last addition zeolites. The breccia-forming disturbances continued after the deposition of the ore bodies (fig. 122).

The epigenetic ores, which are deposits of "moderate to high intensity," are either open-space fillings, of irregular shape, with no distinct walls, or replacement deposits, which lie between clearly defined walls. Some of the replacement lodes are 1,000 feet long and in parts 60 feet wide and contain several ore shoots.

The copper minerals occur in coarse aggregates, in many places as interstitial fillings between coarse quartz-crystal aggregates, or in big pockets in shattered rocks; or they have selectively replaced, often in large blocks, the abundant delessitic chlorite. Prehnite and secondary feldspar aggregates and the quartz-zoisite aggregates of the outer shell resisted replacement.

Chalcocite and bornite predominate over chalcopyrite. Leaching of copper-sulphide aggregates occurs on the margin of ore shoots down to the bottom levels, but not on a large scale.

Graton finds no difference in the physicochemical characteristics of the ore, from the upper to the bottom levels of the Messina mine (2,000 feet).

The accepted theory is that no abrupt change in copper content of the ore is to be expected as mining depth increases, although changes in structural formation, such as the distribution of copper contents over larger areas, may lower the grade of ore locally.

Experiments made by Dr. Heimburg and me showed that apparently isolated copper sulphides are in electrical contact with others hundreds of feet away and that the invisible conductor offers very little resistance to the high-tension current, whereas the same current could not be forced through the moist lode over short distances.

Iron pyrites occur in some ore shoots and seem to be older than the copper sulphides. The ore of both mines is practically free from deleterious minerals. Some molybdenite was at one time observed in some ore shoots, but the molybdenum was driven off in the smelting.

The analysis of the fire-refined copper is as follows:

Copper	99.8900	Sulphur	0.0114
Silver	.0110	Oxygen	.0775
Nickel, cobalt	.0062	Silica	Trace
Iron	.0115		100.0076

The analysis showed no bismuth, lead, antimony, arsenic, tin, zinc, or molybdenum.

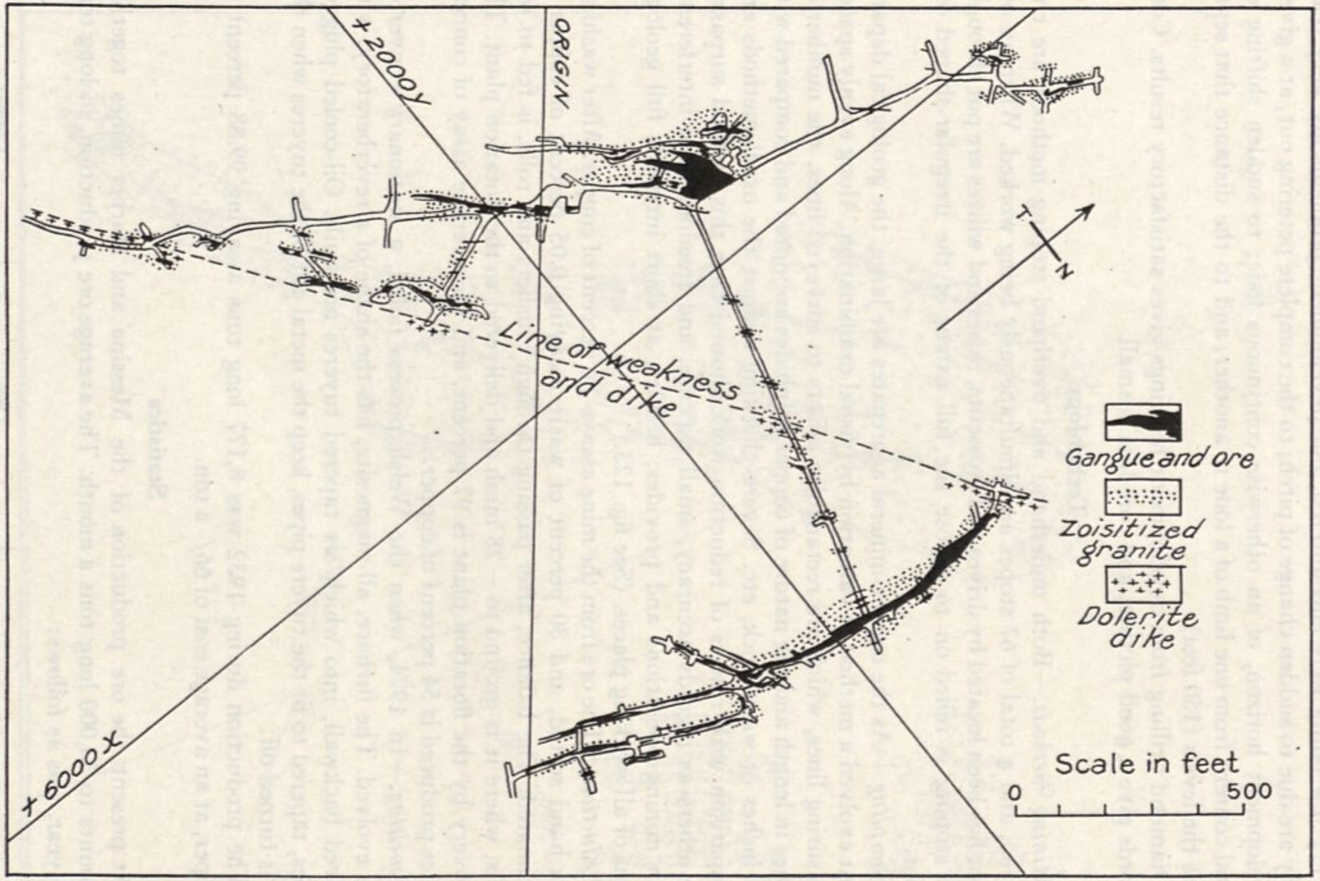

FIGURE 122.—Plan of 6th level, Messina mine, Transvaal, South Africa.

Development

Very few faults were encountered, but development problems are very real. They are due to sudden change of pitch; to the complete petering out, at a given development horizon, of an otherwise continuous lode; to sudden shifting of metal content from one limb of a lode to another; and to the distance that separates the levels (150 feet).

Diamond drilling from development headings gives satisfactory results. Core records give a good picture, and core loss is small.

Technology

Mining methods.—Both underhand and overhand stoping methods are employed, and a total of 67 stopes are simultaneously being worked. When an ore shoot has been located by drives and crosscuts, raises and winzes are put through, and stoping is relied on to expose the full extent of the irregular-shaped ore shoot.

Sampling.—As the copper-mineral aggregates are large, the geological department evolved a method of valuation by visual examination. Along evenly spaced measuring lines, which are rectangular offsets to surveyed lines, the number of inches in length and the nature of copper sulphides are noted and compared with the inches of waste rock, etc. Severe checking against the usual methods and comparison with results of reduction work showed that this method surpasses the others as regards accuracy, small expense, and freedom from interference with mining operations and provides, besides, at short intervals full geologic plans of all working places. (See fig. 123.)

Reduction.—The ore from the mine assays 2.6 percent of copper. After washing, it is hand sorted, and 30 percent of waste assaying 0.05 percent of copper is eliminated. The balance, after passing through crushers and rolls, is fed to rod mills, where it is ground to -28 mesh and delivered to the flotation plant. The recovery by the flotation plant is 97 percent, and the average assay of concentrates produced is 54 percent of copper.

Smelting.—In 1924, when the Welsh process failed, a stationary converter was evolved. The furnace, all magnesite, has the shape of a reverberatory, with curved backwall, into which six tapered tuyeres are built. Oil-cooled plugger pipes, tapered to fit the tuyere pipes, keep the metal out of the tuyeres when the air is turned off.

The production during 1932 was 8,177 long tons assaying 99.88 percent of copper, at an average cost of 66/- a ton.

Statistics

At present the ore production of the Messina and Harper mines together amounts to 33,000 long tons a month. The average ore production, in long tons per year, was as follows:

	Ore	Copper
1914–26	129,338	4,302
1926–31	250,690	7,145
1932	368,258	9,721

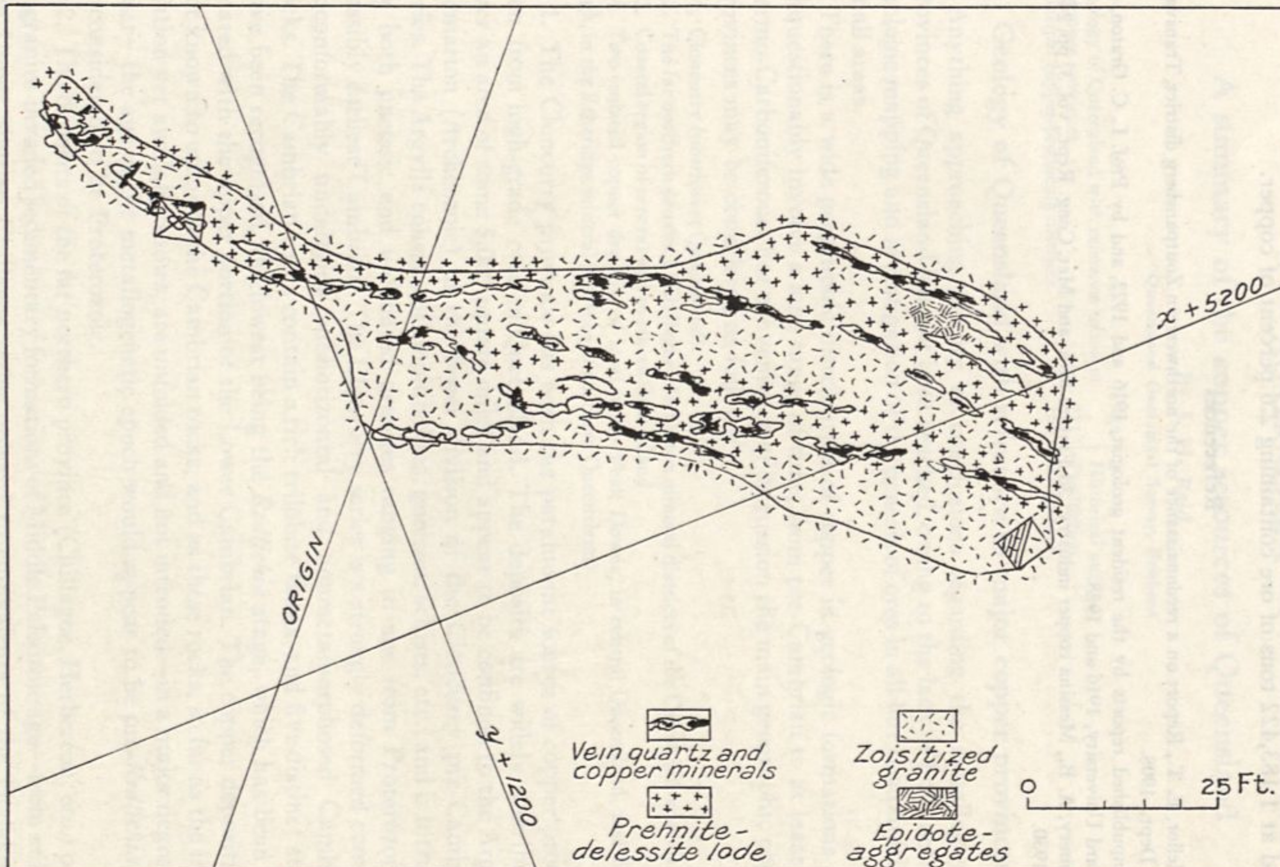

FIGURE 123.—Plan of stope 10–90, K lode, Messina mine, Transvaal, South Africa.

The total ore production since 1914 amounted to 2,915,091 tons of ore, yielding 88,471 tons of copper. The ore reserves at the end of the financial year 1932 stood at 1,183,422 tons of ore containing 2.6 percent of copper.

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AUSTRALASIA

A summary of the copper resources of Queensland

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Geology of Queensland with reference to major copper provinces

Anything approaching finality of conclusions regarding the metallogenetic provinces of Queensland has not been reached, owing to the lack of both detailed geologic mapping and investigation of the genesis of ores in all but comparatively small areas.

There is a wide geographic distribution of copper in geologic formations that unquestionably involve a long range of time, from pre-Cambrian to at least late Permo-Carboniferous. For convenience of discussion the main geographic copper provinces may be considered as follows:

1. Cloncurry (northwest Queensland).
2. The far northern province (Chillagoe-Herberton mineral districts of the Cairns hinterland).
3. Coastal region of central and southern Queensland.
4. Two isolated copper deposits of local note—Peak Downs, in central Queensland, and Einasleigh, in the Etheridge mineral province of northern Queensland.

1. The Cloncurry province has been the paramount source of copper production from high-grade ores in Queensland. The deposits are widely distributed over an area of some 5,000 square miles and appear to be confined to the Argylla formation (Archeozoic) of the lower division of the Cloncurry pre-Cambrian series. The Argylla consists of amphibolites, gneisses, schists, etc., and is intruded by both gneissic and unfoliated granites ranging in age from Proterozoic to possibly earliest Cambrian. The Cloncurry series is a strongly deformed complex unconformably underlying subhorizontal and nonmetamorphosed Cambrian rocks. The Cambrian rocks contain a rich trilobite fauna, and five distinct stages have been recognized, the lowest being the *Redlichia* stage, which has been correlated with the upper portion of the Lower Cambrian. The copper deposits are not known to occur in the Cambrian rocks, and as these rocks, so far as the information yet available shows, are unfolded and not intruded—in a major degree, at least—the age of the metallogenetic epoch would appear to be pre-*Redlichia* and is considered to be Proterozoic.

2. The deposits of the far northern province (Chillagoe, Herberton, etc.) occur in granite-invaded sedimentary formations of Middle Paleozoic age—from at least the Upper Silurian Chillagoe series upward to equivalents of the Hodgkinson series that contain several faunal forms ascribed to the Middle Devonian, though the range of the series may be somewhat higher.

Several if not all of the granites and associated injections of porphyry that intruded the sedimentary formations containing these deposits are apparently

FIGURE 124.—Map of Queensland, showing principal copper deposits.

of late Devonian age, for, so far as known, they antedate the Queensland equivalents of the Kuttung series (Carboniferous of New South Wales).

In the Herberton district the granite intrusions are older than the Kuttung beds, of Lower or Middle Carboniferous age, which are themselves, so far as known, devoid of the metalliferous deposits so characteristic of the sediments on which they lie unconformably. It has not been possible yet to effect a definite separation of the Chillagoe (Upper Silurian), the Herberton sedimentary rocks, and the Hodgkinson (Devonian), so that there is support for the present assumption that in this province the metalliferous series of rocks range in a highly folded but conformable sequence from Upper Silurian to at least Middle Devonian. They were subsequently, between Hodgkinson and Kuttung time, intruded by batholithic granite and hypabyssal masses of porphyry. Besides copper, the mineral deposits in this province are so diverse and are so closely associated with hypabyssal injections of different types from the parent magma that, in addition to postulating a dominant metallogenetic epoch, it is reasonable to assume the possibility of subepochs between Hodgkinson and Kuttung time—that is, tentatively from Upper Devonian to perhaps earliest Carboniferous.

3. In the coastal province of central and southern Queensland copper is distributed in much-intruded Paleozoic sediments and granites, mainly in rocks ranging in age from Devonian to late Permo-Carboniferous. It has been postulated that this metallization may have been confined to the period of the late Permian orogeny and magmatic intrusions, for the Mount Flora copper lodes occur in a granite-invaded area of the Upper Bowen series, a late division of the Queensland Permo-Carboniferous.

This province contains one outstanding gold-copper deposit, at Mount Morgan. The geologic formations of Mount Morgan consist of slightly metamorphosed sediments, intruded by granite and numerous masses and dikes of basic rock of different ages. The age of the Mount Morgan sedimentary rocks has not been accurately determined, but there is reason to believe them Lower Carboniferous or possibly Devonian. The metalliferous rocks in the neighborhood are unconformably overlain by unaltered, subhorizontal lower Mesozoic fresh-water beds, and in adjacent districts the lower divisions of the Permo-Carboniferous (the upper not having been identified) are similarly folded and intruded, so that a prima facie case may be established for a late Permian metallogenetic age for this deposit. Other deposits of less note that have been commercially productive in this elongated coastal area are those of Mount Perry, Mount Chalmers (Great Fitzroy gold and copper mines), Many Peaks, Glassford Creek, and Mount Cannindah.

4. The Peak Downs fissure lode occurs in an area that is otherwise practically devoid of commercial copper deposits. The enclosing rocks consist of schists and phyllites (Clermont series), of either Upper Silurian or Lower Devonian age. The epoch of the granitic intrusions of the region is not definitely known, but it appears to be narrowed down to late Devonian time, and the metallogenetic epoch is most likely to correspond with the later stages of the intrusion.

The Einasleigh copper deposits occur in a mica schist and gneiss complex intruded by aplites and amphibolite. The rocks are comparable lithologically with members of the Cloncurry series and are presumed to be of pre-Cambrian age. The metallogenetic epoch has not been determined.

The oldest copper deposits are unquestionably those in the Cloncurry pre-Cambrian rocks, the epoch being pre-*Redlichia*. This area has not undergone orogeny nor, so far as revealed, major intrusion since earliest Lower Cambrian time, at the very latest, but the Queensland coastal areas have been in the throes of great deformative movements and intrusions of much later age on more than one occasion, and therefore the metallogeny in those areas can have been during a subsequent period to that at Cloncurry. Thus the more easterly deposits (Chillagoe, etc., and Peak Downs) compared to Cloncurry belong to a Middle Paleozoic epoch, and some if not all of the copper deposits of the coastal region, which are still farther east, are of late Paleozoic age.

As a generalization, stability of the continental area advanced eastward with progression of geologic time. Emphasis of this chronologic factor beyond the known time range of the copper deposits is afforded by the occurrence of Mesozoic granites and the disturbed attitude of certain Tertiary formations in the extreme southeastern sector of Queensland.

Principal copper-producing districts

The copper deposits of the Cloncurry district occur entirely in pre-Cambrian gneisses, schists, slates, quartzites, etc., and apparently all in the Argylla division (amphibolite schists, gneisses, etc.). Though these deposits are not noticeably associated with granite intrusions or their derivatives, the granitic outcrops of the region appear to be the uppermost peaks of a batholith underlying Cloncurry. The genesis of the ores is attributed primarily to regional metamorphism, but they were perhaps enriched in parts by ascending metalliferous solutions, with concentration occurring along shear and fissure zones. Enrichment by descending solutions has been notable, and the greater part of the production has come from deposits thus enriched. Nodules of cuprite and native copper were marked surface features in the characteristic limonitic outcrops, which appear almost universally to trend with the strike of the enclosing rocks. The copper minerals chalcocite, malachite, azurite, tenorite, chrysocolla, and chalcopyrite were also more or less abundant. Rarer copper minerals recorded include dioptase, tetrahedrite, and atacamite. Most of the mines worked only oxidized or semioxidized ores, and there is evidence that enrichment of sulphides occurred to a depth of 600 or 700 feet at least. The depths for mine workings are inconsiderable for the production obtained: in most of the important mines they ranged from 400 to 700 feet but in one mine reached more than 1,000 feet. The chief mines and the approximate depth of their deepest workings are as follows: Mount Elliott (480 feet), Hampden (700) feet, Trekalano (600 feet), Mount Oxide (378 feet), Duchess (1,060 feet), and Mount Cuthbert (484 feet). Maximum widths of the major ore bodies appear to have ranged from 50 to 70 feet. The presumably lean primary sulphides have been scarcely exploited, and but little appears to be recorded of their general character, extent, and volume, or potentiality for commercial production.

The far northern province includes Chillagoe-Mungana, Mount Garnet, Herberton, Mount Molloy, and several other producing centers of less importance. Chillagoe is the natural center for a group of producing localities in which argentiferous lead and copper lodes have been worked. The principal deposits of this group are Mungana, Muldiva, Calcifer, and Zillmanton, which lie on or close to the contact of Upper Silurian limestones and intrusive granite and porphyry. These copper deposits, most of them in association with argentiferous lead-carbonate bodies and many with zinc blende, are of two types—(1) contact deposits characterized by the expected association of garnet, magnetite, etc., and (2) irregular-shaped ore bodies occupying solution cavities in massive limestones close to the granites.

Mount Garnet was a large argentiferous copper deposit along a major fissure, on which the main ore body, with a maximum width of 90 feet, assumed a pipe-like form. It was associated with iron ores and garnet in altered sedimentary rocks of Middle Paleozoic age intruded by granitic dikes. At a depth of about 100 feet the cupriferous body changed rapidly to a zinc blende body, and subsequent development work is said, unofficially, to have proved the existence of about 100,000 tons of ore to an additional depth of 100 feet averaging about 20 percent of zinc. This sulphide body is an intimate mixture of zinc blende, pyrrhotite, pyrite, garnet, calcite, and chalcopyrite.

At Herberton cupriferous deposits are associated with complex fissures in sedimentary rocks, either close to granitic contacts or near acidic dikes.

The Mount Morgan gold-copper deposit was described, with a geologic section, by Morton (9, pp. 284–289), from whose account it is seen that the deposit occurred in faulted feldspathic grits and cherty rocks intruded in order by older basic dikes (nonmineralizers), hornblendic granite (primary source of mineralization), and newer basic dikes (not appreciable mineralizers). The approximate maximum dimensions were 1,150 by 720 feet, at the 750-foot level. When major operations ceased, in 1927, the company's estimate of ore left in various portions of the mine was 7,700,000 tons of an average grade of 4.38 pennyweight of gold to the ton and 1.73 percent of copper.

At Mount Chalmers (Great Fitzroy gold and copper mines) an auriferous sulphide ore body has been worked to a depth of almost 500 feet. It occurs within a folded series of Devonian (?) quartzites, etc., intruded by basic dikes. The predominant ore is siliceous and considered to be quartzite impregnated with pyrite and chalcopyrite. Reserves, at the closing down of the mine in 1914, were given by the operating company as 442,500 tons of ore averaging 2.73 percent of copper and 2.27 pennyweight of gold to the ton.

The Many Peaks mine was worked for many years as an accessory deposit for Mount Morgan smelting operations, as it provided basic flux carrying 1.67 percent of copper and 0.16 pennyweight of gold to the ton. The deposit is attributed to replacement of metamorphosed sedimentary and eruptive rocks within a great crush zone. The ore bodies, three in number, are rounded in cross section and have a maximum diameter of 360 feet and a proved depth of 770 feet. The ore was banded pyrite with disseminated chalcopyrite.

In the Peak Downs fissure lode oxidation occurred to a depth of 75 feet, and semioxidation to 120 feet is recorded. The outcrop, the scene of the first discovery of copper in Queensland, was an ironstone gossan with copper carbonates. Enrichment was conspicuous. The greatest depth worked was about 400 feet. The deposit was worked extensively in 1862–78, the production in that period being 100,000 tons yielding 17,000 tons of copper.

Historical outline

The first discovery of an economic copper deposit in Queensland was made in 1862 at Peak Downs, Clermont, and was followed by records of discovery at Cloncurry in 1867 and Mount Perry in 1869. The premier copper-producing deposit of the State, Mount Morgan, was not discovered until 1882. Copper production temporarily reached a high point in the late sixties, owing to the exploitation of the auriferous copper-bearing gossans and secondary ores of Peak Downs. It then decreased greatly and reached its lowest stage during the decade 1890–99. Thenceforward there was a pronounced recovery, due to Mount Morgan returns and subsequently, from 1910 onward, to the exploitation of the rich secondary ores of the Cloncurry province.

The years 1905–20 represent the period of maximum production (mainly from Mount Morgan and Cloncurry), with the peak of 23,655 tons of copper in 1913. The collapse of world market prices in 1919–21 resulted in greatly curtailed production, which has not since recovered to anything approaching its former standard.

Production

The appended returns, except that from Peak Downs, have been compiled from information and statistics recorded in the annual reports of the Queensland Mines Department. These reports date only from 1878, and, although copper production apparently began on a small scale as early as 1862, only scanty records of this metal appear in the earlier annual reports. The total production of metallic copper recorded in the following table from the principal deposits reaches almost 90 percent of the recorded State total of 375,408 tons.

Metal production from principal copper deposits of Queensland

	Ore (long tons)	Copper (long tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (long tons)
Cloncurry province (1884–1932)	1,168,846	120,306	66,701	541,386	....
Hampden (1901–29) [a]	172,239	(b)	(b)	(b)	....
Mount Elliott (1906–19) [a]	169,428	(c)	(b)	(b)	....
Duchess (1905–29) [a]	191,117	(d)	(b)	(b)	....
Trekelano (1908–31) [a]	72,880	(e)	(b)	(b)	....
Mount Cuthbert group and Orphan mine combined (1915–31)	130,171	9,623	(b)	(b)	....
Mount Oxide (1905–31) [a]	12,825	[f]4,531	....	....	....
Far northern province:					
Chillagoe-Mungana district (1889–1932) [g]	705,948	20,717	4,876	6,324,946	48,294
O.K. copper mine (1902–10) [a]	78,771	7,992	(b)	(b)	....
Einasleigh (1901–32) [a]	135,680	7,740	2,247	126,376	....
Mount Molloy (1904–8) [a]	42,000	3,552	(b)	(b)	....
Mount Garnet (1901–3) [a]	62,409	2,898	(b)	574,675	....
Central Queensland:					
Mount Morgan (1883–1932) [a]	7,199,969	114,764	5,028,269	437,968	....
Peak Downs (1863–89) [a]	(h)	[f]17,000	(h)	(h)	....
Mount Perry (to 1899)	(h)	[f]1,550	(h)	(h)	....
Mount Perry (1900–32)	133,450	16,056	23,473	781,905	....
Mount Chalmers (1908–18) [a]	374,735	9,723	49,188	179,971	....
Many Peaks (1910–18) [a]	484,376	[i]8,089	[i]3,875	(h)	....

[a] Individual mine.
[b] Not fully recorded.
[c] Approximately 11 percent ore.
[d] Approximately 15 percent ore.
[e] Approximately 10 percent ore.
[f] Estimated only.
[g] Statistics for Chillagoe-Mungana district include returns from small centers within a radius of 50 miles. The returns are largely based on Chillagoe smelter returns (1901–32), from which it is impossible to segregate copper and lead ores. Most lead ores contain copper and zinc, and the zinc has not been recovered.
[h] Not available.
[i] Calculated from average recoveries.

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Copper deposits of South Australia

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Taken as a whole, South Australia constitutes a metallogenetic province within which copper is the predominant metal, and the total value of the copper production from South Australian mines is greater than that from any other State, being about one-third of that produced within the Commonwealth.

The chief metallogenetic epoch preceded the deposition of the Cambrian sediments in almost every part of the State, the only copper deposits that occur in fossiliferous Cambrian rocks being relatively unimportant veins near Beltana and on lower Yorke Peninsula. These veins may represent the result of the waning phase of the main mineralization, which lingered on at the places mentioned.

The rocks within which the copper lodes are situated differ materially in the several fields. At Moonta they are massive and schistose porphyries; at Wallaroo they are mica schists into which the porphyry is intrusive; in the Mount Lofty and Flinders Ranges the lodes occur in argillaceous siliceous and calcareous sediments and tillite constituting portions of the upper pre-Cambrian sedimentary series.

Much the most interesting feature of the lode occurrences is the pegmatitic character of the vein stuff at Moonta and Wallaroo, where quartz, microcline feldspar, black tourmaline, and biotite are normal gangue minerals. Very little is known regarding the primary ore of most of the other fields, as mining operations ceased with the penetration of the oxidized zone and, in some places, the zone of sulphide enrichment. At Pernatty Lagoon, where a lake deposit is impregnated with chalcocite and subsidiary bornite, covellite, and atacamite, the source of the secondary ore has not been ascertained.

Very much the most productive field in the State has been that of Wallaroo and Moonta, on upper Yorke Peninsula, discovered in 1860, worked on a large scale until the later part of 1923, and still the scene of active mining operations. The value of the total copper output of the field (336,316 tons) is £20,499,542, and the workings extend to depths of 2,982 feet at Wallaroo and 2,520 feet at Moonta. The accompanying generalized and diagrammatic section (fig. 126) indicates the geologic relations of the rocks of the field. The lodes occur in the lower pre-Cambrian complex and may have genetic affinities with the magma from which the massive microcline granite of Arthurton originated.

The ore bodies are situated on simple fractures or fracture zones, most of which are disposed tangentially about a center lying northwest of Arthurton. In the Kadina district some of the lode fractures are radial from the same center. The Moonta lodes occur within three main zones of fracturing in hard, brittle feldspar porphyry that is massive in some places and schistose in others. The individual fractures are themselves complex, and the mineralization of the broken ground was selective. The several lodes have a general parallelism of strike and dip. The ore occurs in shoots, the vertical dimension of many of which has been proved to exceed the stope length.

At Wallaroo the main lode, which is nearly vertical, extends for 2,000 feet with a general strike of N. 80° W. that tends to become more nearly northwest at each end. Other lodes nearby show similar tendencies.

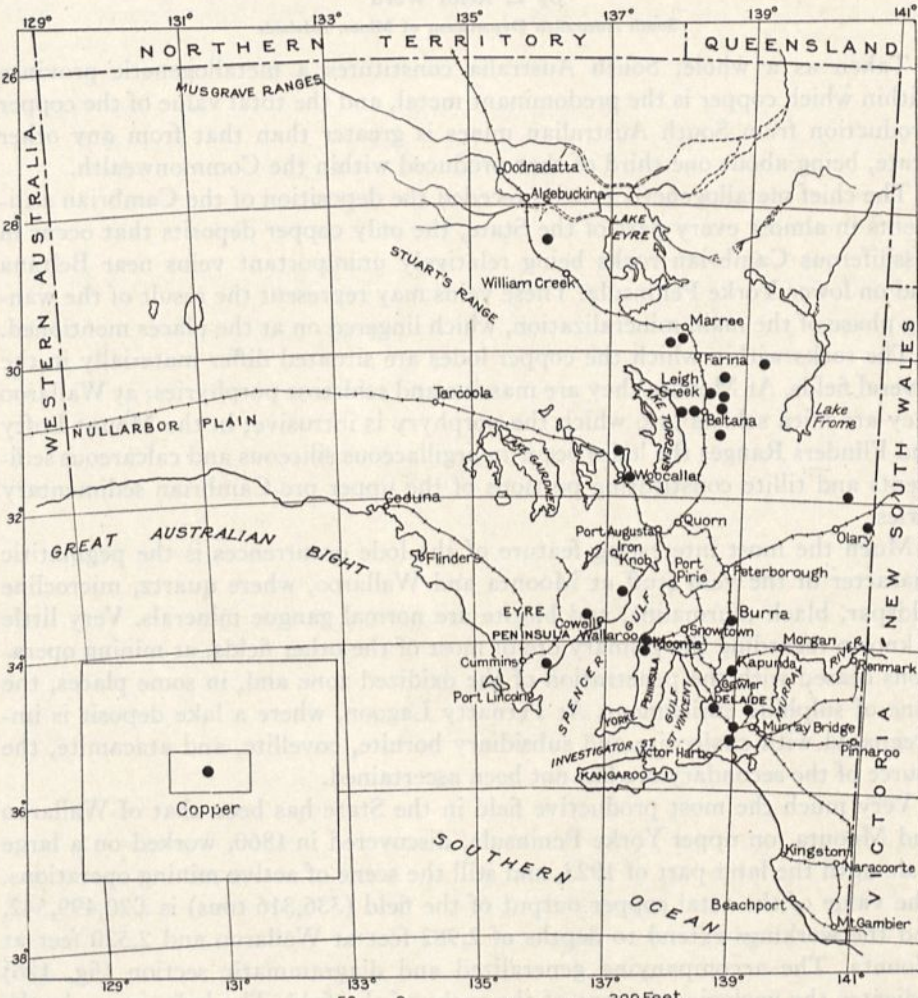

FIGURE 125.—Map of South Australia, showing principal occurrences of copper.

The character of the ore at Wallaroo, although showing definite affinities with that at Moonta, exhibits notable differences. At Moonta there is little pyrite, the characteristic copper ore is bornite, and hematite is present in some lodes. At Wallaroo chalcopyrite is the predominant copper mineral, and both pyrite and pyrrhotite are associated with it. There is a small gold content in the ore of both districts, averaging 5 grains per ton of crude ore.

When the Wallaroo & Moonta Co. stopped mining at the end of 1923 the reserves of ore at Wallaroo in the deepest parts of the mine comprised 246,000 tons of proved ore containing 3.87 percent of copper and 267,000 tons of probable

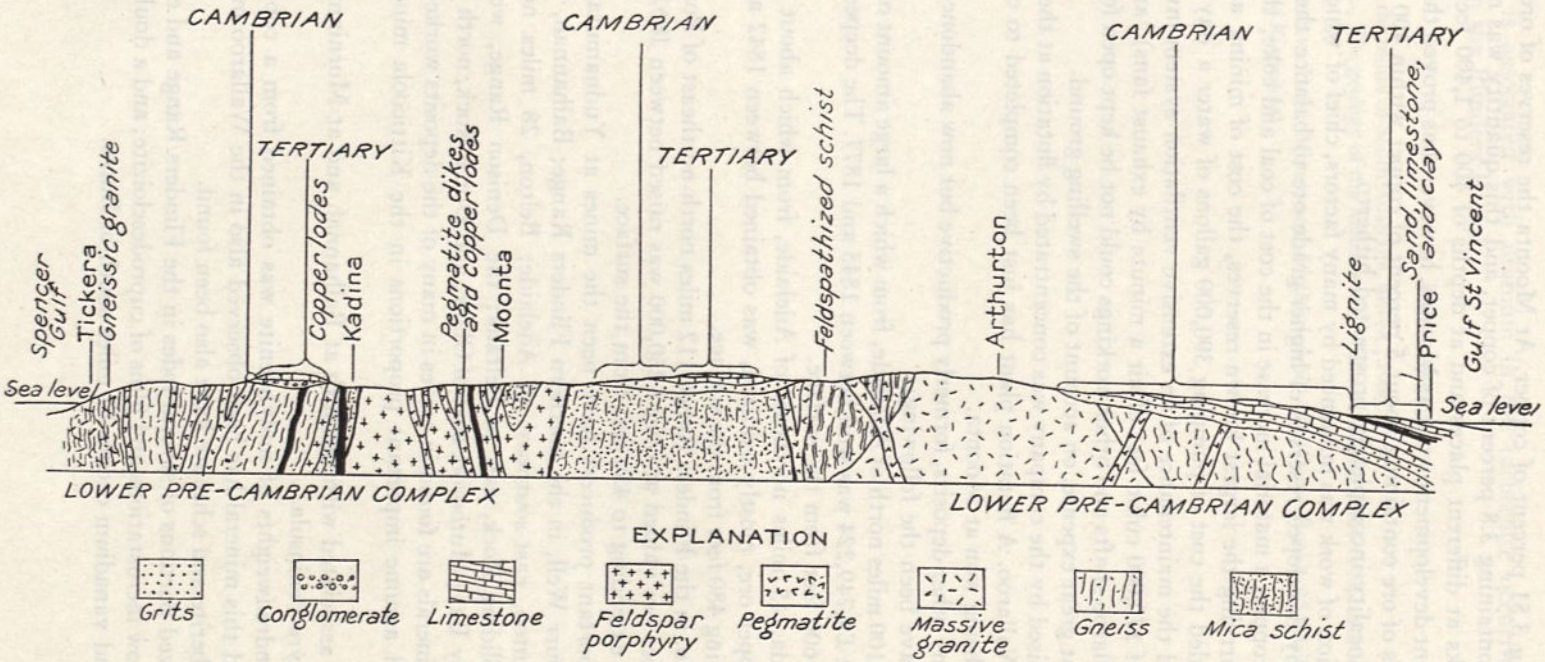

FIGURE 126.—Generalized diagrammatic section of the upper Yorke Peninsula, South Australia.

ore containing 3.51 percent of copper. At Moonta the reserves of ore were only 70,000 tons containing 3.8 percent of copper, and this quantity was made up of isolated blocks at different places and at depths of 400 to 1,400 feet from the surface. Recent development work at Moonta, however, has proved the existence of 35,000 tons of ore containing about 5 percent of copper within 400 feet of the surface in a locality incompletely prospected hitherto.

The cessation of work was influenced by many factors, chief of which were the absence of any developed reserves of higher-grade ore to balance the relatively low price of copper, a material increase in the cost of coal and coke, the depth of the stopes carrying the largest known reserves, the cost of mining at Wallaroo (which included the cost of pumping 390,000 gallons of water a day out of the workings and the maintenance of an extensive ventilation system involving the circulation of 170,000 cubic feet of air a minute by exhaust fans), and the fact that the Wallaroo shafts and other workings could not be kept open for any long period save at great expense, on account of the swelling ground.

The ore raised by the company was concentrated by flotation at the mines and smelted at Wallaroo. A flotation plant has just been completed to concentrate the ore now being won at Moonta.

Of the many other deposits, formerly productive but now abandoned, the most important have been the following:

1. Burra, 100 miles north of Adelaide, from which a large amount of malachite ore valued at £4,749,224 was won between 1845 and 1877. The deepest workings extended to 600 feet from the surface.

2. Kapunda, 45 miles northeast of Adelaide, from which about £1,000,000 worth of copper ore, mostly oxidized, was obtained between 1842 and 1879 at depths reaching 480 feet from the surface.

3. Blinman, in the Flinders Range 112 miles north-northeast of Port Augusta, whence copper ore valued at over £250,000 was raised between 1862 and 1907, from depths extending to 450 feet from the surface.

Other important producers have been the mines at Yudnamutana, Mount Rose, and Burr Well, in the northern Flinders Range; Balhannah, Callington, and Kanmantoo, east-southeast of Adelaide; Belton, 28 miles northeast of Carrieton; Sliding Rock, east of Beltana; the Denison Range, west of Lake Eyre; Tumby Bay; Mutooroo, east of Olary; and Dome Rock, north of Olary.

Copper minerals are found in traces in many of the deposits worked primarily for gold and assume important proportions in the Kitticoola mine, south of Palmer.

Copper is associated with bismuth at Balhannah and at Murninnie, north of Cowell on Eyre Peninsula.

A few hundredweights of molybdenite was obtained from a copper lode at Moonta, and this mineral has been observed also in the Wallaroo mines, where traces of ferberite and scheelite have also been found.

The oxidized portions of several lodes in the Flinders Range and elsewhere in the State show incrustations and films of cuprodescloizite; and a double sulphide of copper and vanadium occurs 14 miles south of Burra.

Copper is associated with uranium in the torbernite occurring at Mount Painter, in the Flinders Range.

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Mining Review, Dept. Mines, nos. 27 (Mutooroo), 37 (Dome Rock), 45 (Blinman), and 53 (Kapunda and Kurinnola).

The copper resources of Tasmania

By P. B. Nye

Tasmania Mines Department, Hobart

Geology of Tasmania

The oldest rocks of Tasmania are schists and quartzites of Proterozoic age. The lower Paleozoic sedimentary rocks include the dark slates and quartzites of the Cambrian or Cambro-Ordovician system, the purple slates and breccias of the Dundas series (probably Ordovician), and the conglomerates, sandstones, slates, and limestones of the Silurian system. Devonian sedimentary rocks are absent, but conglomerates, sandstones, shales, and limestones were formed during the Permo-Carboniferous period. Between the end of the Silurian and the beginning of the Permo-Carboniferous sedimentation, intrusions of granite, syenite, porphyries, dolerites, gabbros, and ultrabasic rocks occurred. Mineralization accompanied the intrusions, and this was the major metallogenetic epoch of Tasmania.

Conglomerates, sandstones, mudstones, feldspathic sandstones, and coal seams were formed during the Triassic period. The State was a land surface during Jurassic time unless some of the rocks assigned to the Triassic were deposited during the Jurassic period. Cretaceous sediments are unknown. During late Triassic or Jurassic time intrusions of dolerite (diabase) occurred on a large scale.

The Tertiary sedimentary rocks include marine sandstones and limestones of Miocene age and sands of upper Pliocene age; and fresh-water sand, clay, gravel, etc., of mid-Tertiary age. Basalt flows occurred during the Oligocene and Pliocene, while alkali porphyries were intruded at Cygnet.

Glacial and fluvioglacial deposits were formed during the Pleistocene epoch. Marine and fresh-water sediments were probably also laid down in estuaries around the coast.

The major metallogenetic provinces are two:

(*a*) West and northwest coast. This province is characterized by the presence of Devonian (?) granite and porphyries intrusive into lower Paleozoic sedimentary rocks. The mineral deposits include tin, silver-lead, zinc-lead-silver, and copper, and the principal mining fields are Mount Lyell, Zeehan, Heemskirk, Read-Rosebery, Tullah, Waratah, Magnet, Balfour, and Moina. The tin deposits are associated with the granite or acidic intrusive dikes. The copper and zinc-lead-silver deposits are associated with the acidic to intermediate porphyries in the main portion of the province.

(*b*) Northeast coast. This province is characterized by Devonian (?) granite intrusive into Cambro-Ordovician sedimentary rocks. The principal mineral deposits are those of tin and gold and to a less extent tungsten. The tin deposits are restricted almost entirely to the granite, and the gold to quartz reefs in the sedimentary rocks.

Geology of the copper-producing districts

Mount Lyell.—The Mount Lyell district is occupied by Silurian sedimentary rocks intruded by Devonian (?) porphyries in the form of a long dike of irregular shape and with a considerable range in width. The eastern portion of the dike has been rendered schistose by shearing. The western boundary of the dike exhibits intrusive contacts with the Silurian sandstones, but it is possible that extensive faulting has occurred along the eastern margin, which is in contact with conglomerates. The main fault, if present, has a general north-south direction, and numerous transverse faults have also been reported. Several small dikes penetrate the Silurian rocks west of the main dike.

The ore bodies are restricted to the shear zone on the east side of the dike. They are of two main types—lenticular bodies of pyrite and mineralized bands of schists, etc.

The pyritic bodies include the Mount Lyell and South Lyell deposits. The Mount Lyell body was elliptical, being 800 feet long and 200 feet wide at the outcrop, and tapered gradually downward to a rounded base, the probable depth being 730 feet. The South Lyell body probably represents the faulted extension of the Mount Lyell body. The pyritic bodies are very pure, consisting essentially of pyrite with some galena and less sphalerite, the gangue (chiefly quartz and barite) being present in only small amounts. At first ore containing 2.35 percent of copper was mined, but the grade decreased and the average content became 0.5 percent of copper, with 1.5 ounces of silver and 0.04 ounce of gold to the ton. The outcrop of the Mount Lyell body was represented by hematite rich in gold, and the mine was originally operated as a gold mine until the hematite was depleted.

The mineralized bands of schist, etc., include the ore bodies of the North Lyell, Crown Lyell, Lyell Blocks, Royal Tharsis, and Lyell Comstock mines. They form large ore bodies of considerable length and vertical extent but irregular in shape and with a considerable range in width. The North Lyell body has been mined to a depth of 1,300 feet from the surface, and the Tharsis has been proved to a depth of 1,100 feet. The ore consists of schist or quartzite, with bornite, chalcopyrite, and pyrite.

The following figures for the reserves were supplied by the general manager, Mr. R. M. Murray:

Reserves in Mount Lyell district

Mine	Ore (tons)	Copper content (percent)
North Lyell	700,000	4.75
Lyell Comstock	700,000	3.00
Crown Lyell	500,000	2.00
Royal Tharsis	2,500,000	2.25
Prince Lyell	5,000,000	1.00

Jukes-Darwin field.—The Jukes-Darwin field lies south of the Mount Lyell field and has the same geologic features. The ore bodies are similar and occur under similar geologic conditions and structural relations. The field has not been exploited, owing to difficulties of transportation and absence of high-grade deposits.

Mount Balfour.—The Mount Balfour field is occupied by Cambro-Ordovician sedimentary rocks intruded by Devonian (?) granite and amphibolites. The copper lodes are enclosed in the sedimentary rocks and the amphibolites. The metallic minerals are chalcopyrite and pyrite in a gangue of quartz, chlorite, sericite, and dolomite. Very little production has taken place.

Heazlewood.—The Heazlewood district is occupied by intermediate basic and ultrabasic igneous rocks intruded in Cambro-Ordovician and Silurian sedimentary rocks. The copper deposits consist of bornite and chalcopyrite in the ultrabasic rocks, probably as segregations. The deposits are small, and the production has been very slight.

Exploration, mining, and technology

The Mount Lyell ore body was worked by open cut to a depth of several hundred feet and then by underground methods. The North Lyell and adjacent bodies were worked from vertical shafts, but in 1928 an adit 6,952 feet long and 9 by 9 feet in section was driven to connect with the 1,100-foot level, and this adit now serves for transporting the ore from the North Lyell and Royal Tharsis mines. The Lyell Comstock mine has been opened by adits.

At each level certain drifts and crosscuts are driven, and this is followed by diamond drilling to outline the ore body at that level.

All ore is trammed to the reduction works at Queenstown, which have a capacity of 1,000 tons a day. The bulk of the ore is subjected to wet concentration (flotation), and the concentrates are sintered and smelted in blast furnaces. The matte is treated in converters, and the blister copper is refined electrolytically for production of high-grade cathode copper.

History

The history of copper mining in Tasmania began with the discovery in 1883 of the hematite overlying the Mount Lyell ore body. After being worked as a gold mine, the underlying pyrite was revealed. On the basis of reports by experts, it was decided to work the deposit for copper, and pyritic smelting was the process adopted. Smelting began in 1896.

A boom followed the discovery of the Mount Lyell ore body, and the whole of the district was pegged and numerous companies formed. The North Lyell was the most successful and was first worked in 1895, but the rich deposits were not found till 1897. This company carried out mining and smelting, but in 1903 it was amalgamated with the Mount Lyell Mining & Railway Co., which later acquired by purchase or otherwise all the deposits in the district.

As the Mount Lyell pyrite decreased in copper content, it became used as a flux only, but its use has now been discontinued. The ore is now obtained from the North Lyell (including Royal Tharsis and Crown Lyell) and Comstock mines. The pyritic smelting was eventually abandoned, and concentration of the ores began.

The blister copper was forwarded to Port Kembla until 1928, when the company installed its own refining plant.

Production

The production is illustrated by the figures for 1932, during which 380,800 tons of ore was mined. Of this, 13,622 tons of North Lyell ore was sent direct to the smelter, and the remainder was concentrated to yield 45,535 tons of concentrates. Including a small amount of purchased ore, 59,168 tons of copper-bearing material was smelted for a production of 11,101 tons of blister copper containing 10,995 tons of copper, 161,633 ounces of silver, and 4,865 ounces of gold, with an approximate value of £441,222.

The total amount of ore treated by the Mount Lyell Co. to the end of 1932 was 9,493,399 tons. This yielded 260,867 tons of blister copper containing 258,079 tons of pure copper, 14,470,902 ounces of silver, and 406,545 ounces of gold. The total dividends paid amount to £5,251,569.

The statistics of the Mines Department show the total production from Tasmania to December, 1931, as follows:

Copper and silver in blister copper to 1918	£13,778,527
Copper ore to 1918	577,873
Copper matte	133,736
Copper (from 1919)	6,257,872
	20,748,008

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Copper in Victoria

By Department of Mines, Geological Survey

Melbourne

Copper deposits in the State of Victoria are of minor extent. The chief formation worked was a fissure lode at the Thomson River near Walhalla. From 1865 to 1867 the production was 41½ tons of regulus having an average copper content of 50 percent. From 1877 to 1881 the production was 643 tons of smelted copper. The total value of the copper produced from the mine is recorded as £50,000. The richest ore was a solid lens of chalcopyrite traversing Silurian strata. East of the lode a large diorite dike containing much chalcopyrite occurs. At a depth of 70 feet below the lower tunnel the ore terminated. The strike is N. 20° W. and the dip 84° E.

Some platinum was produced from the copper regulus of the old smelting plant. Assays made by P. G. W. Bayly from bore cores in 1909 show that the ore from the mine contains 16 grains of platinoid minerals to the ton with each 1 percent of copper.

The sulphide ores of Bethanga contain a little copper sulphide and occur in fissure lodes traversing metamorphic strata. The lodes strike north-northeast and dip slightly east to vertical. The lodes are from 1 to 2 feet wide, with an occasional bulge. A typical sample of the Bethanga ore yields arsenic, 10 percent; copper, 2 percent; sulphur, 25 percent; gold, 1½ ounces to the ton. From 1883 to 1911 the yield from the main line of lode (The Gift) was 60,879 ounces of gold from 53,014 tons of ore.

At Accommodation Creek, Croajingolong, a lode striking S. 30° E. and dipping 60° NE. has been prospected a little, but development has been hampered by the inaccessibility of the district. The lode is 3 to 5 feet wide and is of the fissure type, traversing altered Ordovician strata. The outcrop has been traced for 20 chains, and to the west granodiorite occurs. For 30 feet on the hanging wall of the lode patches of malachite and azurite, with some chalcopyrite, occur. The aspect of this lode occurrence has been considered promising, but transportation is difficult at present.

At Sardine Creek, Croajingolong, 14 miles north of Orbost, in the parish of Nerran, there is a copper lode of the fissure type associated with cherty rocks and granodiorite. It strikes N. 30° E. and dips 70° W. It is only 8 to 12 inches in width, and the copper ore is associated with pyrites and galena.

Another copper occurrence in the Sardine Creek district is seen at Wallaby Creek, where small quartz veins contain chalcopyrite, an assay from which shows copper, 19.1 percent; silver, 17 pennyweight 8 grains per ton; gold, 2 pennyweight 15 grains per ton.

Copper ore has also been recorded from Corryong, Mount Deddick, Gibbo River (Mammoth mine), and Mount Tara.

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Copper deposits of Western Australia

By T. Blatchford
Geological Survey of Western Australia, Perth

History

The history of mining in Western Australia began with the finding of profitable copper deposits in the Northampton district in 1842. The first reported export of copper was a consignment which was shipped from the port of Geraldton 3 years later. Though copper deposits of one form or another are widely distributed throughout a large portion of the State, the production of copper has been, except at a few places, very small compared with that of some of the sister States of eastern Australia.

Up to the present time the largest producers have been the Whim Creek copper mine, in the West Pilbara gold field; the Anaconda copper mine, near Mount Morgan; two groups of mines in the Phillips River district, in the southern part of the State; and to a lesser degree a second group scattered over the Northampton district and closely associated with the more productive lead mines of that area. The relative productivity of these few centers may be seen in the accompanying table of statistics.

Geologic characteristics

The occurrence of copper deposits in Western Australia may be placed geologically under three broad headings—(1) impregnated shear zones in sedimentary rocks, (2) impregnated shattered or shear zones in igneous rocks, (3) lodes of the fissure type, which are usually associated with quartz. All the rocks in which copper occurs are pre-Cambrian.

Of the first type the best examples are the Whim Creek and Mons Cupri deposits. In the Whim Creek mine the copper occurs in bunches, veins, and lenses, traceable for 4,000 feet at the surface and to a depth of 120 feet vertically, or 400 feet on the dip. The country rock throughout is a fine-grained gray slate which shows distinct signs of shearing, the long axes of the copper lenses being parallel to the shear planes, though many veins of copper ore cut across them. The Mons Cupri mine is in much the same formation but has not proved so productive.

The best examples of the second group are the chief producers of the Ravensthorpe belt and the Anaconda mine. In both these localities the copper ore occurs in shattered or sheared greenstones. In the Ravensthorpe belt the deposition of copper has obviously been caused by the intrusion of a very extensive batholith of soda-bearing granite. The mines occur around and at no great distance from this granite mass.

Of the third class probably the best examples are the copper- and gold-bearing siliceous veins at Kundip and in the Phillips River district. These deposits have all the characteristics of ordinary quartz veins or siliceous gold-bearing lodes.

Methods of exploration

All the copper lodes in the State have been discovered by testing the outcrops, usually first brought to notice by the prevailing green color. Except at the Whim Creek and Mons Cupri mines the ore has been exploited by ordinary shaft sinking and usual practices of underground development.

At Whim Creek the dip of the lode was so low that one section was actually exposed by surface denudation. Nearly all the ore has been won from adits into the side of the hill, from which short drifts were made as occasion warranted. The same condition occurred at Mons Cupri, where adits were driven right through the hill.

Technology

At most of the mines the copper was recovered by fairly coarse crushing either by hand or by machinery, and then hand picking for bagging and shipment. Probably the first attempts to improve on these crude methods was the erection of an extensive plant at Whim Creek to put into operation a magnetic separator. This process was really based on two principles—the selective adhesive property of grease or heavy oil on metallic concentrates, and the magnetic property of magnetic iron ores.

The process was as follows: Copper was crushed fine (20 to 25 mesh) and agitated with water as a fairly thin pulp. To this were added small pellets of heavy oil or grease impregnated with finely ground magnetic iron ore. After violent agitation the mixture was passed over tables and under cross-traveling belts, above which were placed strong electric magnets. The theory was obvious. The oil was to collect the metallic mineral contents, and the adhering magnetite was to be the cause for the magnetic attraction. Unfortunately in practice the process failed.

About the same time ordinary straight-out smelting and converting was introduced in the Phillips River district, and the ores thus treated included much of the gold-bearing low-grade copper ore of Kundip. These copper works have recently been abandoned, and copper production has practically ceased in the district.

At Whim Creek a second attempt was made to recover copper in a large way by introducing the Pechey process for treatment of some 80,000 tons of hand-picked oxidized ore lying in the waste heaps. This process, which had been successfully applied in other places on similar ore, failed at Whim Creek. The only important principle involved in the process is the regeneration of the ferrous sulphate solutions to the ferric state by the introduction of sulphur dioxide fumes in the presence of air and copper oxide. Otherwise the process is merely a heap leaching process comparable with the old Rio Tinto method.

In more recent years an attempt was made at Ravensthorpe to extract copper from both oxidized and sulphide ores by a process known as the "metallic contact process for the extraction of copper from ores." In this process the ore is first slimed and then agitated with a solution of sodium chloride and ferrous sulphate, heated to 170° F. Metallic iron (sponge iron) is then added in small quantities to the hot pulp. By the time all the required amount of sponge iron has been added, all the copper in the pulp has been precipitated in the metallic form and in a very finely divided state. The pulp and precipitate is then transferred to an oil-float machine by which the metallic copper is recovered. Unfortunately, though an expensive plant was erected, it was never brought to the stage of production.

Production

The following table gives statistics of the production:

Copper produced in Western Australia

Gold field	District	Ore (tons)	Metallic copper (tons)	Value
West Kimberley		109.52	25.92	£1,709
Pilbara	Marble Bar	32.87	5.41	386
	Nullagine	14.00	6.97	480
West Pilbara	Roebourne	4,064.70	785.60	68,653
	Whim Creek	77,534.75	10,123.78	665,853
	Croydon	604.00	108.65	7,333
	Egina	542.00	104.15	6,643
Ashburton		351.07	97.13	6,408
Peak Hill		1,015.11	353.31	32,212
East Murchison		238.56	38.42	4,364
Murchison	Meekatharra	968.46	131.59	10,714
	Day Dawn	55.56	8.10	522
Yalgoo		38.40	5.57	413
Northampton mineral field		24,019.17	1,832.80	119,451
Yandanooka mineral field		171.55	27.63	1,889
Mount Margaret	Eulamina (Anaconda)	46,314.05	4,194.56	213,835
	Murrin	1,543.62	253.44	16,985
	Burtville	2.85	.29	26
North Coolgardie	Goongarrie	6.12	.82	51
East Coolgardie	Boorara	50.67	6.22	330
Phillips River		95,727.13	8,367.75	588,115
State generally		18.61	3.81	249
		253,422.77	26,481.92	1,746,621

first slimed and then agitated with a solution of sodium chloride and ferrous sulphate, heated to 170° F. Metallic iron (sponge iron) is then added in small quantities to the hot pulp. By the time all the required amount of sponge iron has been added, all the copper in the pulp has been precipitated in the metallic form and in a very finely divided state. The pulp and precipitate is then transferred to an oil-float machine by which the metallic copper is recovered. Unfortunately, though an expensive plant was erected, it was never brought to the stage of production.

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Copper produced in Western Australia

Gold field	District	Ore (tons)	Metallic copper (tons)	Value
West Kimberley		109.32	25.92	1,709
Pilbara	Marble Bar	32.67	9.41	380
	Nullagine	14.00	0.97	490
West Pilbara	Roebourne	4,064.70	785.00	68,653
	Whim Creek	70,931.75	7,123.76	666,838
	Croydon	104.00	108.65	7,333
	Egina	542.00	104.15	6,743
Ashburton		433.99	91.13	6,808
Peak Hill		1,015.11	231.31	12,217
East Murchison		278.59	58.42	4,164
Murchison	Meekatharra	968.40	131.59	60,714
	Day Dawn	43.50	8.10	522
Yalgoo		18.30	5.57	413
Northampton mineral field		38,079.12	1,813.50	129,838
Yandanooka mineral field		171.84	37.61	1,599
Mount Margaret	Eulaminna (Anaconda)	40,714.05	4,194.36	213,895
	Morgans	2,323.62	283.44	16,086
	Burtville	0.85	.29	26
North Coolgardie	Goongarrie	6.77	.82	31
East Coolgardie	Boorara	30.56	5.22	230
Phillips River		95,727.11	8,367.75	588,113
State generally		18.61	1.81	249
		257,432.67	26,461.93	1,746,021

TECHNOLOGY

Copper-mining methods and costs in North America[1]

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Selection of a mining method

In general, the mining method selected for exploiting any given ore body is governed by the type of the deposit. From a miner's standpoint copper deposits may be placed in four general classes—the so-called "porphyries," massive sulphide or replacement deposits, veins, and bedded deposits.

The ore bodies at the porphyry mines are generally flat-lying and relatively near the surface. Where the overburden is relatively thin an open-cut method of mining is used. Where the cost of stripping would offset the lower costs attainable by open-cut work the deposits are mined by an undercut block-caving method. The sulphide copper minerals in these ore bodies are disseminated throughout a siliceous gangue; this permits caving the ore without danger of ignition. Moreover, the deposits are fractured; this allows the ore to cave and break into small fragments when it is undercut.

In massive sulphide deposits the physical characteristics of the ore and wall rock are usually the prevailing factors in the selection of the method of mining. At Ducktown, Tennessee, where the ore is hard and the wall rock strong, an open-stope method is successfully used. In the Campbell ore body of the Copper Queen mine at Bisbee, Arizona, the ore and walls have less strength than at Ducktown but are strong enough to permit a semishrinkage method. At the United Verde mine natural conditions are less favorable than in the Campbell ore body, and a cut and fill method supplemented by square-setting is employed. Where ore bodies lie near or at the surface they may be mined by open-cut or glory-hole methods, irrespective of their physical characteristics.

The size, dip, and shape of the ore body, together with the structural strength of the ore and wall rocks, determine the stoping method to be used for mining veins or bedded deposits. Where the rock will stand without support, an open-stope method is likely to be used. If greater weights must be sustained, shrinkage, cut and fill, or square-set methods are employed, the choice depending upon

[1] This paper has been abstracted from a forthcoming Bureau of Mines bulletin on copper mining in North America, prepared by E. D. Gardner and C. H. Johnson.

the degree of support required. In heavy ground top slicing may be used. Because of their shape deposits in veins or beds usually are not amenable to extraction by a caving method such as is used in porphyry ore bodies.

The first consideration in the selection of a mining method is, of course, safety of the operation. Aside from the humanitarian viewpoint, a method that permits a low operating cost but causes a high accident rate may not be as economical as a method which entails a higher direct cost but by which accidents are kept at a minimum.

Other considerations in the selection of a method, aside from the physical characteristics of the ore and wall rock and safety, are grade of ore and selling price of the metal, climate and topography, effect of ground movement and the necessity of maintaining the surface, necessity for selective mining, rate of oxidation of ore minerals, scale of operation, and availability of timber and skilled labor.

Mining methods at typical mines

The copper industry in the United States and northern Mexico went through a period of expansion during 1927, 1928, and 1929, culminating in 1929, the year of maximum production. In Canada, however, expansion continued through 1930 and 1931. Beginning in 1930, many of the United States companies began to curtail production, and then one by one a large proportion of the mines closed. In the first half of 1933 few copper mines were being operated at capacity. Many were working part time, principally to keep men employed. Although wages and supplies were abnormally high in 1929, costs per ton of ore mined were moderate on account of the large tonnages handled. During 1930 labor efficiency had increased and costs of supplies were lowered; on the whole lower costs were attained than in 1929, despite the smaller tonnages mined. Further economies were made in 1931 and 1932 at some mines. On account of curtailments and shut-downs in 1931 and 1932, the years 1929 and 1930 are considered in this paper as giving a better cross section of methods and costs at copper mines than later periods. Moreover, at the time of writing operating data for 1931 and 1932 are largely lacking.

The total normal daily capacity of all the copper mines in North America (in 1933) is about 250,000 tons of ore. The principal producers of copper are the so-called "porphyries." The ore bodies at these mines are of low grade, and relatively large tonnages are handled daily. Either an open-cut or a block-caving method is used. About half of the copper ore mined each year in the United States is obtained by open-cut methods; over a quarter is obtained by caving.

The massive sulphide, vein, and bedded deposits in North America are mined by the following methods, named in the order of production of copper by each: Open stope, square set, shrinkage, cut and fill, top slicing, glory holing, sublevel caving, and leaching in place. Aside from the porphyries most of the underground mines employ two or more methods of mining.

Open-cut mining

A list of the open-cut copper mines, together with production and geologic data and mining practices, is shown in table 1. The first mine of this list to be

UTAH COPPER MINE, BINGHAM, UTAH.

developed was the Utah Copper (pl. 41), in 1907, and the last the Flin Flon, in 1930.

Sections of the Utah Copper and United Verde ore bodies and pits are shown in figures 127 and 128 respectively. A plan of the Chino workings is shown in figure 129.

The same general plan of operations is followed at all the open-cut mines. After being blasted the ore or waste is loaded by power shovels into trains running on standard-gage tracks. The shape of the ore body and the topography of the surrounding country govern the manner in which the mine is laid out.

The physical character of the ore and rock influences drilling and blasting practices, which have been developed to fit local conditions, and limits the overall slope of the sides of the pits. More variations exist in breaking the ground than in other practices at the open-cut mines.

Undercut block-caving method

The undercut block-caving method is used for mining large disseminated deposits of considerable horizontal extent, usually over 100 feet thick. The ore bodies at the Inspiration mine (fig. 130) are representative of those mined by this method (1). It is used where open-cut mining is not applicable and where the loss of ore and the dilution by waste will be more than compensated for by the relatively low mining costs. From 10 to 20 percent of the ore may be lost owing to the limitations of the method. Several companies using this system of mining, however, have plans for leaching the caved material remaining after underground operations have been completed.

As the ore bodies mined by this method are of relatively low grade, the work must be done on a large scale to be profitable. Operations are conducted on three levels—the level on which the ore is undercut; the grizzly level, on which the ore is drawn from the stopes; and the haulage level, on which the ore is transported to the shaft or surface. The ore after being undercut is drawn through regularly spaced draw raises on the grizzly level. After passing through the grizzlies the ore drops through gathering raises to the haulage level below, where it is loaded into cars. Table 2 shows the normal daily tonnage, yearly production, and size of the ore bodies at each of the mines using the undercut block-caving method. The spacing of development work preparatory to caving at seven of the mines is given in table 3.

A perspective view of the Morenci block-caving system is given in figure 131 and a plan of the grizzly and haulage levels in figure 132. The method of undercutting (3) at the Miami mine is shown in figure 133.

The deposits being mined by the undercut block-caving method were drilled and their depth, thickness, and horizontal extent determined before plans were drawn for mining. Although major changes cannot be made in a method when it is once established for mining a block of ore, continued improvements and refinements have been made in practice. Moreover, as experience has been gained important improvements have been made in the general methods, when applied to new ore bodies.

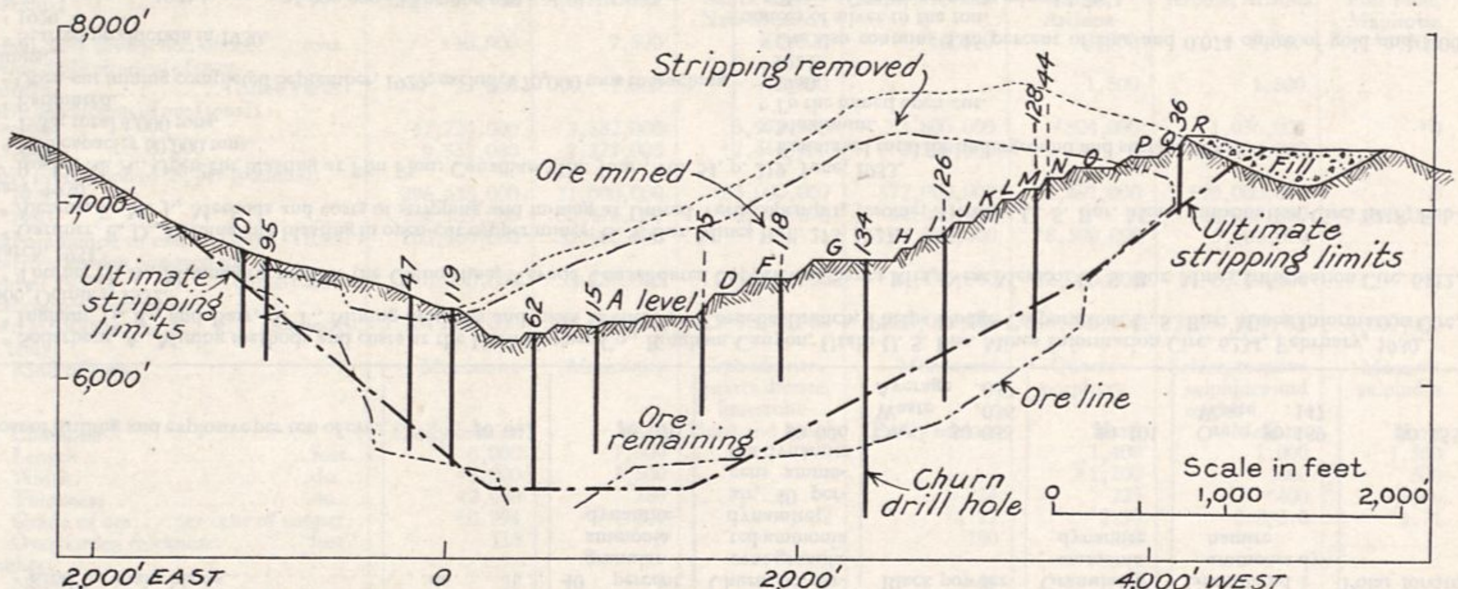

FIGURE 127.—Typical east-west section through Utah Copper mine, Bingham, Utah.

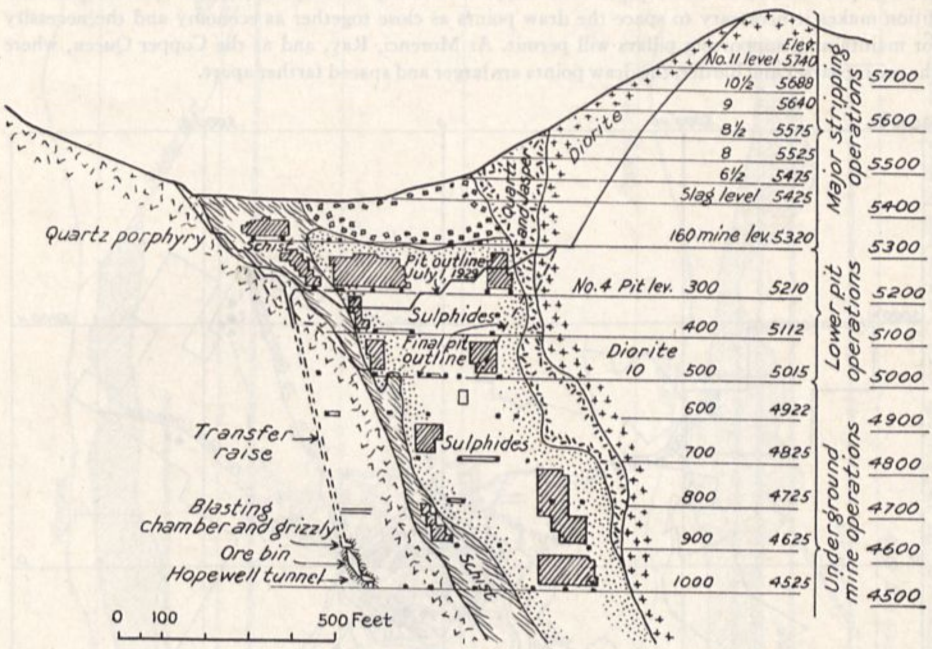

FIGURE 128.—Typical section of United Verde pit, Jerome, Arizona.

The principle of mining by the undercut block-caving method has been stated as follows (4):

The main features in mining by an undercut block-caving method are (1) the breaking of the ore by the force of gravity, thereby eliminating drilling and blasting in stopes, and (2) drawing the ore under control through raises into haulage cars, thereby doing away with the necessity for shoveling.

The method is characterized by an intensive production of ore from a relatively small area, which permits repetition of a number of simple operations. A thorough study of this work makes possible standardization of nearly all operations and efficient working of the mine.

Caving is induced by undercutting and cutting off the blocks from surrounding ground. The ore is drawn through openings uniformly spaced below the block.

By undercutting is meant the blasting and partial or complete removal of a layer of ore across the base of the column to be mined so as to permit the ore above to cave and break by gravity. The undercutting practice is not uniform at all mines, and the methods in use have been developed mainly to fit the particular conditions existing at each place.

Undercutting is supplemented by either cutting off the block entirely from the surrounding ground or weakening it along its boundaries so as to assist the caving action and confine it to the block mined.

For perfect drawing the draw points should be closely and regularly spaced, but a compromise must be made between close spacing, which increases ore recovery and reduces dilution, and wider spacing, with resulting economy in preparatory costs and operating repairs. The character of the ground is the controlling factor in drawing practice.

In the original Inspiration ore body and at the Miami and Ruth mines the ore breaks finely and tends to pack and when drawn pipes vertically, with little spread beyond the draw points. This condition makes it necessary to space the draw points as close together as economy and the necessity for maintaining supporting pillars will permit. At Morenci, Ray, and at the Copper Queen, where the ore is coarser and harder, the draw points are larger and spaced farther apart.

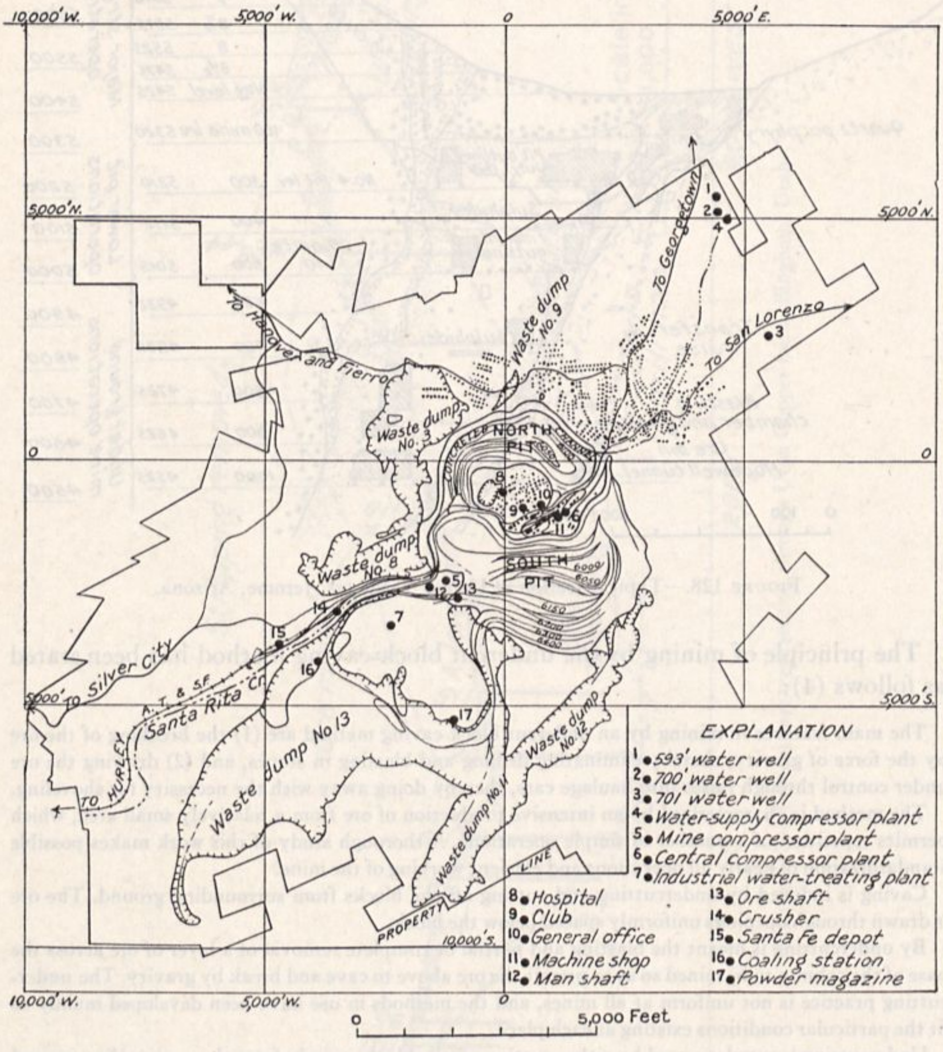

FIGURE 129.—Property map of Chino mine, Santa Rita, New Mexico, showing pit outline.

Dilution is caused by the irregular movement of ore and capping toward the drawing points forming pipes of waste, which may reach a draw point in advance of the top boundary of the ore, or by waste being drawn in from the sides or ends of a block. Dilution may also be caused by the general infiltration of fine capping down through coarsely broken ore. Moreover, in all caving there is a gradual mixing of the ore and capping as the ore is drawn down. If properly drawn a large part of the ore comes to the chutes clean. After dilution starts the proportion of waste increases and that of the ore decreases.

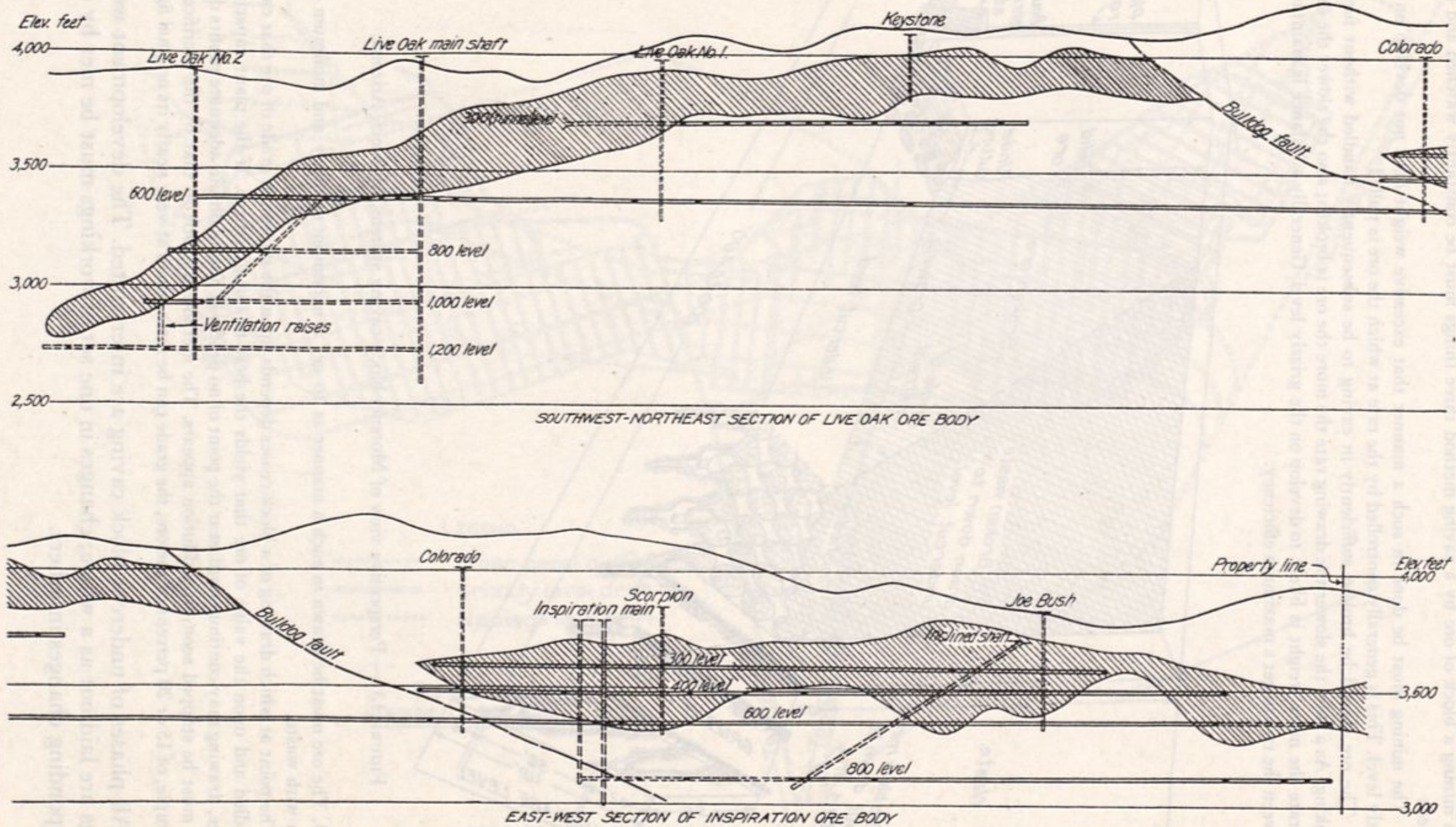

FIGURE 130.—Sections of Live Oak and Inspiration ore bodies, Inspiration, Arizona, showing shafts and haulage levels. Vertical and horizontal scales identical.

In mining a block of ore by a caving method three things must be constantly watched and controlled:

1. The mining must be done in such a manner that excessive weight does not develop on the grizzly level. This is generally controlled by the rate at which the ore is pulled.

2. The ore should be broken sufficiently in caving to be subsequently handled without further breaking. As a rule, the slower the drawing rate the more the ore is broken; also the slower the drawing rate the more weight is likely to develop on the grizzly level. Generally a balance is maintained between the two to get a maximum efficiency.

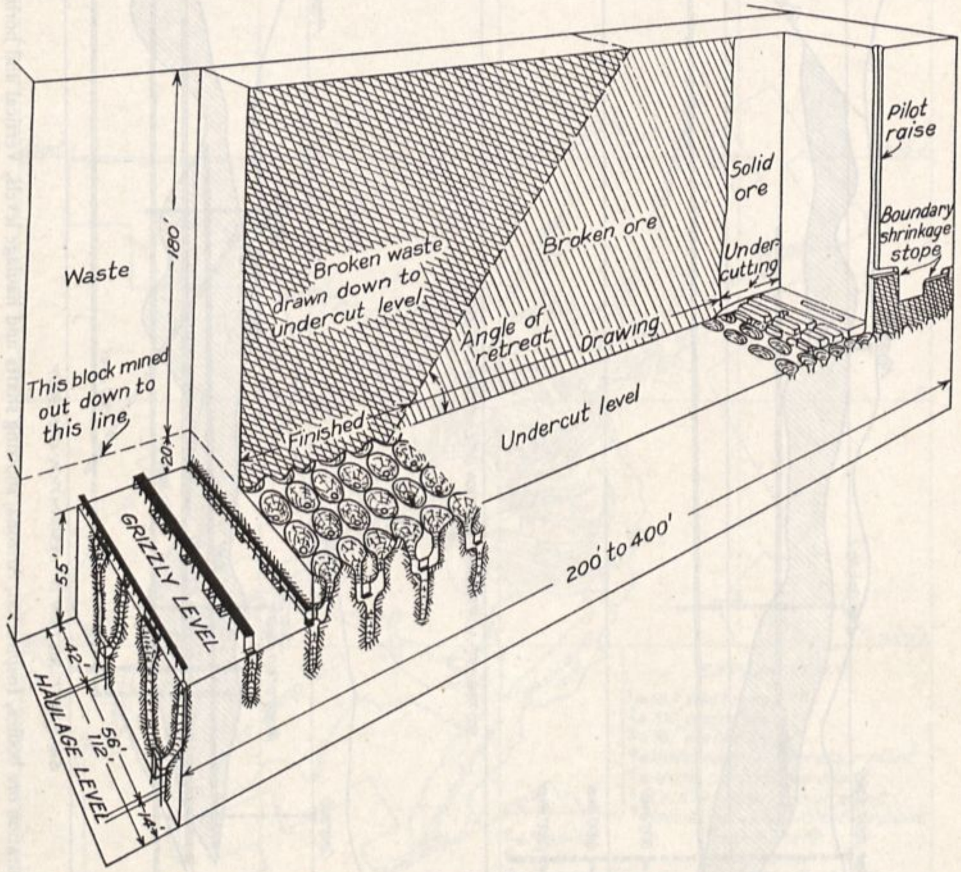

FIGURE 131.—Perspective view of Morenci block-caving system, Morenci, Arizona.

3. The ore must be drawn in such a manner as to get a maximum recovery and minimum dilution with waste.

The point at which drawing of a block ceases depends upon the minimum grade of ore that can be handled and upon the value of ore that yields the best financial returns. If the plant capacity is large, drawing may continue until near the point of no profit. If not, to obtain adequate profits drawing must be stopped soon after dilution appears. The method is elastic in that by the sacrifice, for example, of 15 or 20 percent of the ore, the grade can be maintained at very nearly its original figure.

All phases of undercut block caving are interrelated. The development workings are laid out as a whole; changes in one set of workings must be met by corresponding changes in others.

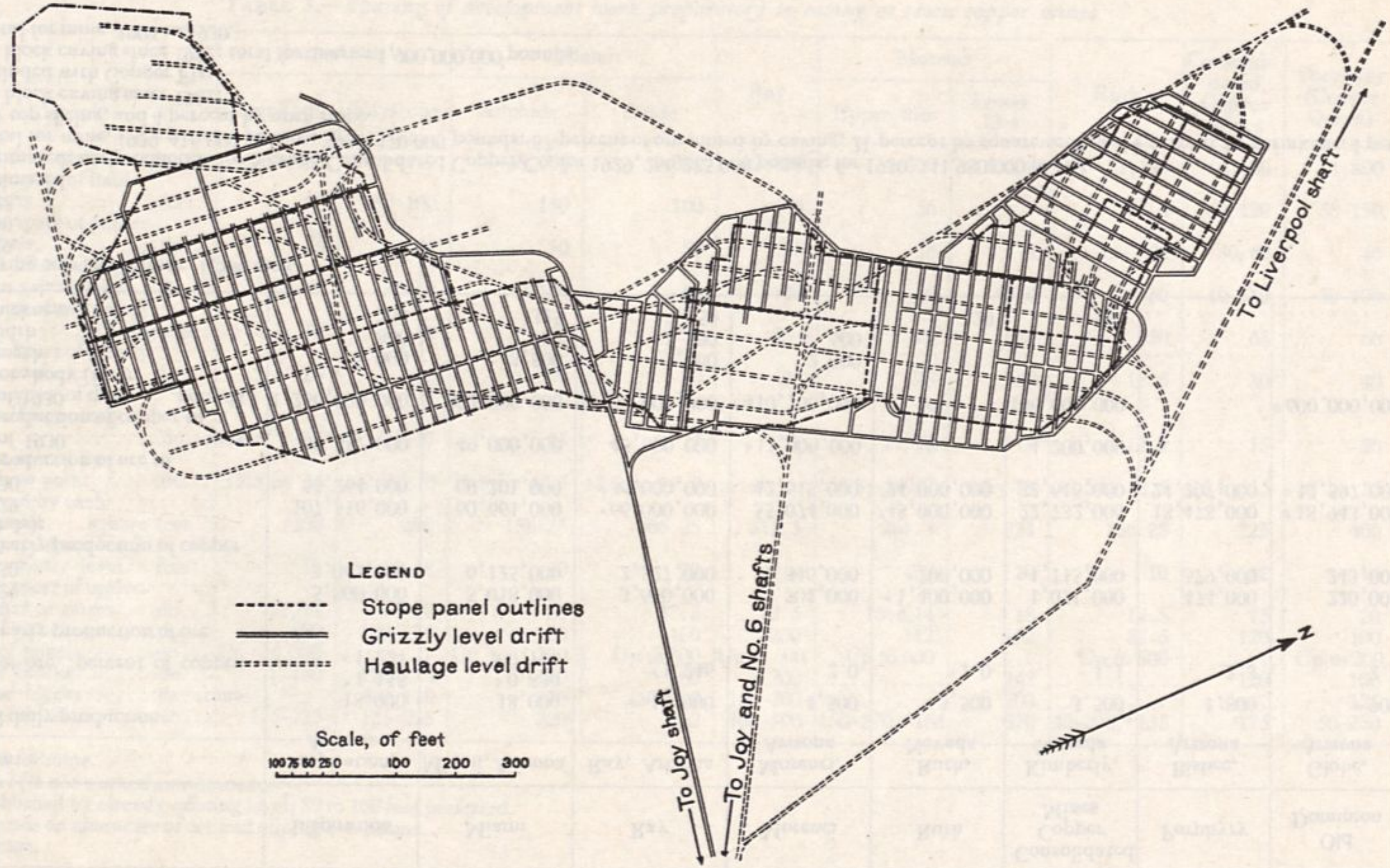

FIGURE 132.—Plan of grizzly and haulage levels, Morenci mine, Morenci, Arizona (2).

TABLE 2.—*Production data of North American copper mines using undercut block-caving methods*

	Inspiration	Miami	Ray	Morenci	Ruth	Consolidated Copper Mines	Porphyry	Old Dominion
Location	Inspiration, Arizona	Miami, Arizona	Ray, Arizona	Morenci, Arizona	Ruth, Nevada	Kimberly, Nevada	Bisbee, Arizona	Globe, Arizona
Normal daily production of ore . . . tons	18,000	18,000	12,000	4,500	3,500	3,500	1,800	[a] 900
Grade of ore . . percent of copper	[b] 1.155 [c] 1.224	[b] 0.830 [c] 0.716	[d] 1.246	2.0	[e] 2.0	1.1	2.3	2.5
Total yearly production of ore (tons):								
1929	5,800,000	5,018,000	3,610,000	1,704,000	[e] 1,400,000	1,071,000	474,000	220,000
1930	3,042,000	6,125,000	2,327,000	1,346,000	[e] 700,000	1,115,000	579,000	243,000
Total yearly production of copper (pounds):								
1929	107,516,000	60,661,000	[e] 66,000,000	55,074,000	[f] 48,000,000	22,732,000	18,478,000	[g] 18,943,000
1930	65,264,000	69,201,000	[e] 36,000,000	42,618,000	[f] 24,000,000	32,616,000	24,207,000	[g] 17,597,000
Total production of ore to end of 1930 . . . tons	69,387,000	49,000,000	45,800,000	[h] 11,000,000	(i)	4,200,000	. . .	. . .
Total production of copper to end of 1930 . . . pounds	1,256,000,000	1,002,000,000	1,103,000,000	[j] 410,700,000	(i)	106,000,000	. . .	[k] 600,000,000
Size of ore body (feet):								
Length	8,000	3,500	7,000	2,000	. . .	. . .	. . .	. . .
Width	800	2,700	1,500	600	. . .	. . .	. . .	. . .
Thickness	200	325	250	. . .	120	175	. . .	. . .

[a] Caving only; total mine, 1,500 tons.
[b] 1929.
[c] 1930.
[d] 1928.
[e] Estimated.
[f] Estimated; net production for Nevada Consolidated Copper Co. for 1929, 266,275,000 pounds; for 1930, 141,980,000 pounds.
[g] Total for mine, 1929, 416,000 pounds; 1930, 470,000 pounds; 57 percent of ore mined by caving, 21 percent by square-setting, 14 percent by shrinkage, 4 percent by top slicing, and 4 percent by open stope.
[h] By block caving since 1922.
[i] Included with Copper Flat.
[j] By block caving since 1922; total for district 1,900,000,000 pounds.
[k] Total for mine, 1904 to 1930.

TABLE 3.—*Spacing of development work preparatory to caving at seven copper mines*

	Inspiration		Miami		Ray	Morenci		Ruth	Consolidated Copper Mines	Porphyry (Copper Queen)
	Standard	Keystone	Sulphide	Oxide		Upper lifts	Lower lifts			
Normal daily output...tons..	[a] 18,000	....	18,000	3,000	12,000	4,500	[b] 4,500	3,500	3,500	1,800
Distance apart of haulage drifts............feet..	90	50–100	150	100	50	56	....	87.5	60, 120	50–150
Distance apart of gathering raises............do...	25	25	50	50	25	28	72	25	30, 60	40
Distance from haulage level to grizzly level...do...	45–60	30–60	100	66	40	50	[c] 240	50	40–110	50–100
Inclination of gathering raises............degrees..	50	50	55	54	55+	75	68	50	65	60
Distance apart of grizzly drifts or raises........feet..	25	25	50	50	25	28	36	12.5	30	40
Distance apart of draw points along grizzly drifts................do...	16	15–17	25	25	25	21, 24	18	12.5	15	20
Plan area served by each draw point.......do...	12.5 by 16	12.5 by 16	12.5 by 12.5	17.5 by 17.5	....	14 by 18.67	18 by 18	12.5 by 12.5	15 by 15	20 by 20
Area served by each draw point....square feet..	200	200	156.25	306.25	312.5	261.3	324	156.25	225	400
Distance undercut level above grizzly level...feet..	18	16–18	30	20	....	20	20	10	12	16
Distance apart of undercut drifts or raises....do...	11, 14	15–17	25	17.5	12.5	18.6,14	18	12.5	15	20
Width of panels........do...	180	120–170	150	150	200	112	162	87.5	120	100
Length of panels.......do...	Up to 1,000	....	Up to 1,200	Up to 300	Up to 600	Up to 600	....	Up to 500	....	Up to 200
Width of blocks........do...	180	120–170	150	150	200	....	162	....	120	100
Length of blocks.......do...	[d]	100–120	150	150–300	150–200	....	200	....	....	[e] 125
Height of blocks.......do...	125–225	125–225	320	262	100–300	150–270, [e] 164	270	40–200, [e] 135	[e] 175	60–250

[a] Total for mine.
[b] Both lifts not worked simultaneously.
[c] Established by already existing level; 80 to 100 feet preferred.
[d] Depends on character of ore and mining conditions.
[e] Average.

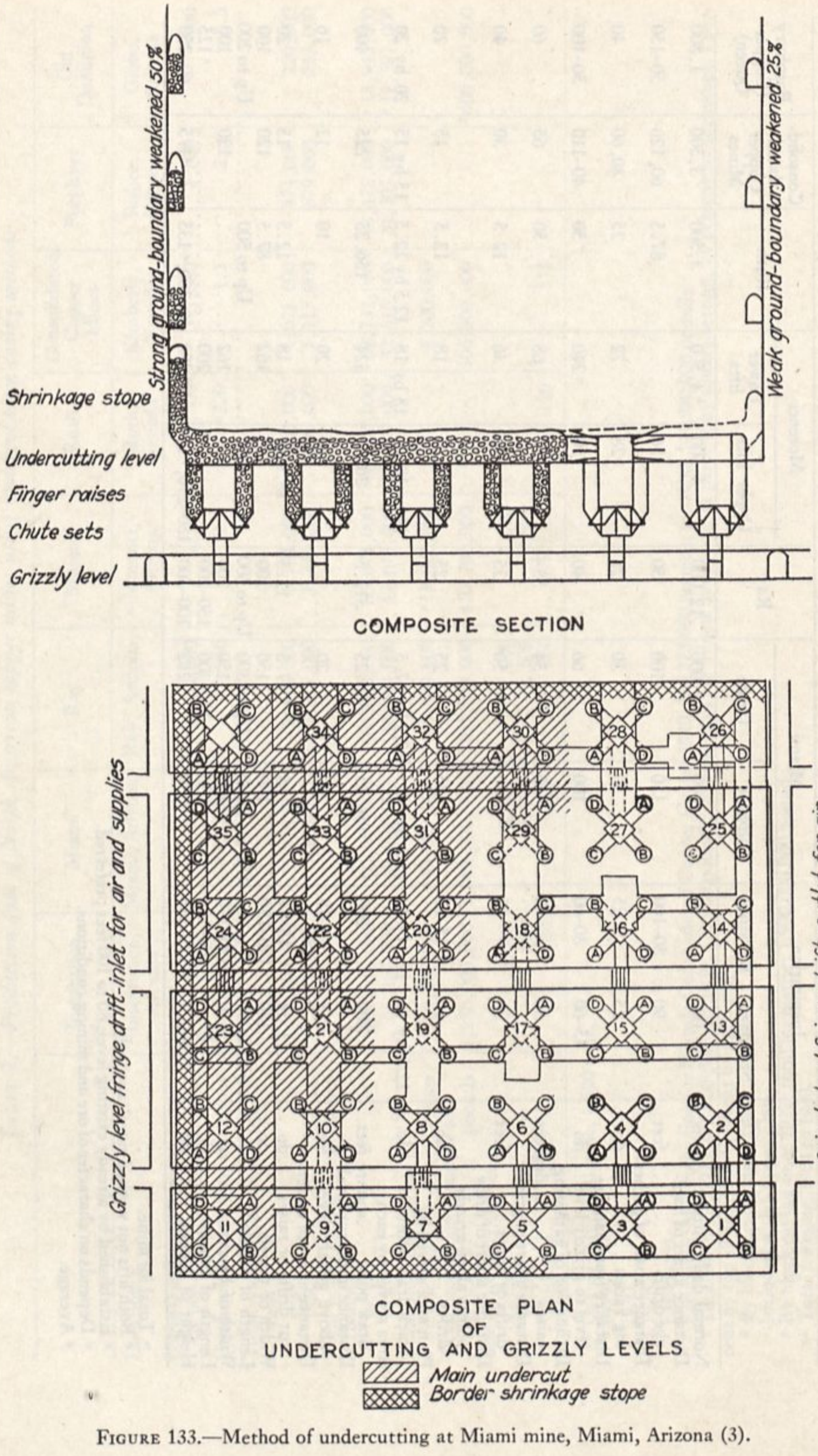

FIGURE 133.—Method of undercutting at Miami mine, Miami, Arizona (3).

Methods of undercutting: Stopes are usually undercut either by running a checkerboard system of drifts and crosscuts and blasting the pillars (fig. 133) or by belling out the finger raises to intersect, or by a combination of both methods. At Ray (5) the cut-off workings consist of a series of low shrinkage stopes with pillars between; the cut-off is completed by blasting the pillars. In hard ore a system that will insure a complete undercut should be used; otherwise the back may not cave. Moreover, a small area of unbroken ore under a stope may transmit excessive pressure from the broken ore to the workings below. The first block developed in the Miami oxide ore body failed to cave after being undercut; it was necessary to initiate caving by blasting charges in "powder drifts" run in the ore above the undercutting level. Where the ore is mined in panels, transverse shrinkage stopes may be run across them to induce caving, particularly when trying to initiate the first caving in the panels.

After undercutting, the ore is drawn slowly at first, until it starts to cave freely, and afterward at the rate that best suits the nature of the ground and the requirements for ore. Whatever the rate of drawing, it should be continuous in order to avoid packing of the ore. The ore should be drawn uniformly, particularly during the early stages of the operation, to assure a satisfactory recovery. The contact between the ore and the broken overlying capping should be an even plane, whether horizontal or inclined. If the early drawing is not done uniformly the mass of ore may cave along some plane of weakness, causing chimneys or cavities that may extend into the capping and allow it to mix with the ore. After the main mass of ore has been thoroughly broken and the block has caved to the surface, the result of subsequent irregular drawing is not as serious as it would have been earlier.

Open-stope method

The open-stope method is used in ground that will stand without support other than pillars or casual stulls over spans corresponding to the size of stopes being worked. In small ore bodies the application of the system may be very simple; in large deposits, however, stoping must be done according to prearranged plans if the best results are to be obtained. Pillars left between open stopes may be mined by other methods.

General data on representative North American copper mines using open-stope methods are shown in table 4.

The method has found its greatest application in Michigan, where it has been used from the surface to a depth of 8,000 feet on the dip. The method used on the Conglomerate lode is the best example of the use of the open-stope method in an extensive bedded deposit of moderate dip. As depth was attained the manner of attack was changed from advancing to retreating (6). The retreating system of mining is shown in figure 134.

At the Kearsarge mine, on the Amygdaloid lode (7), beginning at the boundary, 37-foot stope sections with 5-foot "rib pillars" between are mined to the level above. At the Osceola mine open stopes with pillars are used (8).

Sublevel stoping, a variation of the open-stope method, is feasible only in large ore bodies with strong walls. By this method economies in stoping costs in wide ore bodies are attained, and the safety of operation is increased. A rather elaborate preparatory program is necessary, however, before a stope can be put on full production. The method is used at Ducktown, Tennessee, where it was developed, and at the Flin Flon, Sherritt-Gordon, Hidden Creek, and Noranda mines in Canada. The method as used in 1932 at the Burra Burra mine, Ducktown (9), is shown in figure 135.

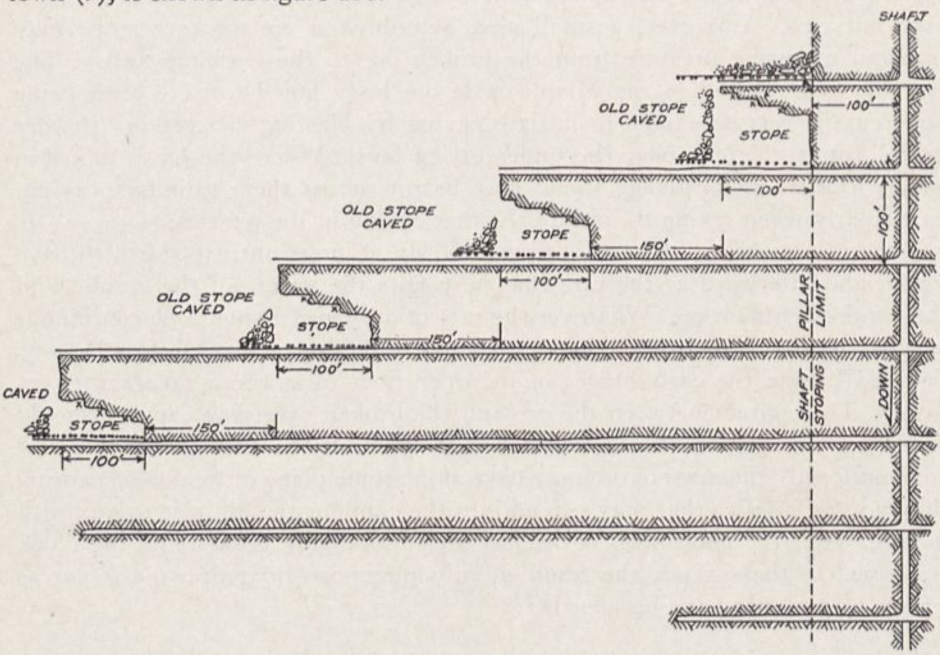

FIGURE 134.—Retreating stoping system, Conglomerate lode, Michigan.

Stoping at the Burra Burra is started on the second sublevel at one end of the block by slabbing off the sides of the subdrift to expose the walls; a footwall raise is then benched out to the full width of the ore. Benching proper begins by cutting a 5-foot slab from wall to wall at the height of the sublevel and then extending the cut downward to a depth of 6 feet. A second 5-foot cut is then taken as before at the subdrift level, after which the first bench started is extended downward to the top of the sublevel below. The ore is then broken by successive downward slices, retreating from one end of the stope to the other. The same process is repeated on the next level above. The work on a lower level is kept far enough ahead of that above to insure that the men are always working under the protection of solid ground. Previous to 1932 two benches were maintained at each sublevel, as shown in figure 135. Taking the ore off in a single slice as described above is an improvement in the practice.

At the Hidden Creek mine (10) a similar system is used except that the ore is broken down from spiral raises rather than from sublevels. At the Noranda (11) benching is done from inclined raises.

At the Mary mine (12) the ore is broken by underhand drilling into a raise. The method is in effect an underground glory hole.

Table 4.—*General data for representative North American copper mines using open-stope methods of mining*

	Conglomerate	Kearsarge	Osceola	Mohawk	Quincy	Seneca	Burra Burra	Flin Flon	Sherritt-Gordon	Hidden Creek	Bonanza[a]	Noranda	Mary
Location	Lake Superior district, Michigan	Lake Superior district, Michigan	Lake Superior district, Michigan	Lake Superior district, Michigan	Lake Superior district, Michigan	Lake Superior district, Michigan	Ducktown, Tennessee	Flin Flon, Manitoba	Cole Lake, Mantiboa	Anyox, British Columbia	Anyox, British Columbia	Noranda, Quebec	Isabella, Tennessee
Normal daily production of ore ... tons	2,800	4,000	3,000	2,000	1,500	600	[b] 1,600	[c] 3,000	[d] 1,800	[e] 5,500	280	2,800	[f] 400
Total yearly production of ore (tons):													
1929	841,000	1,270,000	1,009,000	620,000	208,000	139,000	[g] 473,000	0	0	[h] 1,582,000	(h)	422,000	[g] 109,000
1930	842,000	1,194,000	899,000	473,000	451,000	228,000	...	(i)	0	1,423,000	88,000	849,000	...
Total yearly production of copper (pounds):													
1929	35,377,000	35,744,000	18,237,000	20,043,000	4,459,000	3,000,000	[j] 13,586,000	0	0	[h] 36,746,000	(h)	51,625,000	[j] 2,788,000
1930	[k] 41,000,000	[k, l] 47,000,000	(m)	13,300,000	10,940,000	4,858,000	...	[i] 2,088,000	(n)	27,714,000	2,837,000	76,142,000	...
Total production of ore to end of 1930 ... tons	[k] 61,000,000	[k] 43,000,000	[k] 28,500,000	17,244,000	...	...	...	...	...	[o] 16,627,000	(o)	1,542,000	...
Total production of copper to end of 1930 ... pounds	[k] 3,050,000,000	[k] 890,000,000	[k] 495,000,000	354,173,000	765,628,782	...	...	...	...	[o] 508,827,000	(o)	161,076,000	...
Kind of deposit	Bedded	Bedded	Bedded	Bedded	Bedded	Bedded	Replacement	Replacement	Replacement	Shoots near contact	Shoots near contact	Sulphide lenses	Replacement
Length of ore body ... feet	10,000	Extensive	Extensive	Extensive	Extensive	Extensive	2,300	2,600	5,200	300–2,000	1,700	...	2,000
Thickness of ore body ... do	10–20	18	...	20	4–20	12	4–180	[a] 400	15½	50–350	[a] Width 200, thickness 60	[p] 50	150
Dip of ore body ... degrees	36–38	36	37	38	37–50	32	50–75	60–70	51	...	Flat	...	65
Grade of ore[q] ... percent of copper	2.2	1.4	0.9	1.5	1.1	1.1	[r] 1.6	[s] 1.7	[t] 3.5	1.2	...	5.1	[r] 0.8
Depth of ore mined ... feet	[u] 5,220	[v] 5,000	[v] 4,500	...	[v] 9,100	3,050	1,600	...	...	1,330	(w)	...	900
Level interval ... do	[v] 100	[v] 150	[v] 120	[v] 100	[v] 160	...	196	100, 150, 200	[v] 200, 350	100–250	...	...	100, 150
Chute spacing under stopes ... do	...	21	25	...	20	...	40	...	35	50	Branch raises, irregular	25	100 by 100
Length of stopes ... do	100	37	120	100	50	...	40–340	...	500	100–300	Large, irregular	45	60
Method of attack or advance	Retreating	Retreating	Retreating	...	...	...	Underhand, from sublevels	...	Underhand, from sublevels	Underhand, back, and breast, from spiral raises	Breast and back	Benching from incline raises	Underhand
Method of handling ore in stopes	Scrapers	Gravity and scrapers	Gravity and scrapers	...	Gravity and scrapers	...	Gravity	...	Gravity	Gravity	Scrapers and gravity	Scrapers and gravity	Scrapers and gravity
Where stopes silled	On level	10 feet above drift	10 feet above drift	On level	22 feet above level	...	At sublevels	...	At sublevels	15–30 feet above drift	On footwall	...	Top stope

[a] Maximum.
[b] Pillars constituting 15 percent of the ore are mined by cut and fill.
[c] 1,000 tons daily from underground mine.
[d] Mill capacity.
[e] 5 or 10 percent of ore mined by glory hole.
[f] Pillars amounting to 48 percent of ore mined by other methods.
[g] 1928.
[h] Hidden Creek production for 1929 includes about 100,000 tons from Bonanza, which started in that year.
[i] Started production in 1930; in 1931 produced about 31,000,000 pounds.
[j] 1928; total for property.
[k] Approximate.
[l] Includes production for Osceola mine in 1930.
[m] Included in production for Kearsarge in 1930.
[n] Started production in 1931 with about 15,000,000 pounds.
[o] Includes production of Bonanza in 1929 and 1930.
[p] Average.
[q] Recovery in Michigan mines.
[r] Iron and sulphur content utilized.
[s] Also about 35 percent of zinc, which is recovered.
[t] Also considerable zinc, which was not recovered.
[u] 9,200 feet on incline.
[v] On incline.
[w] Only one level.

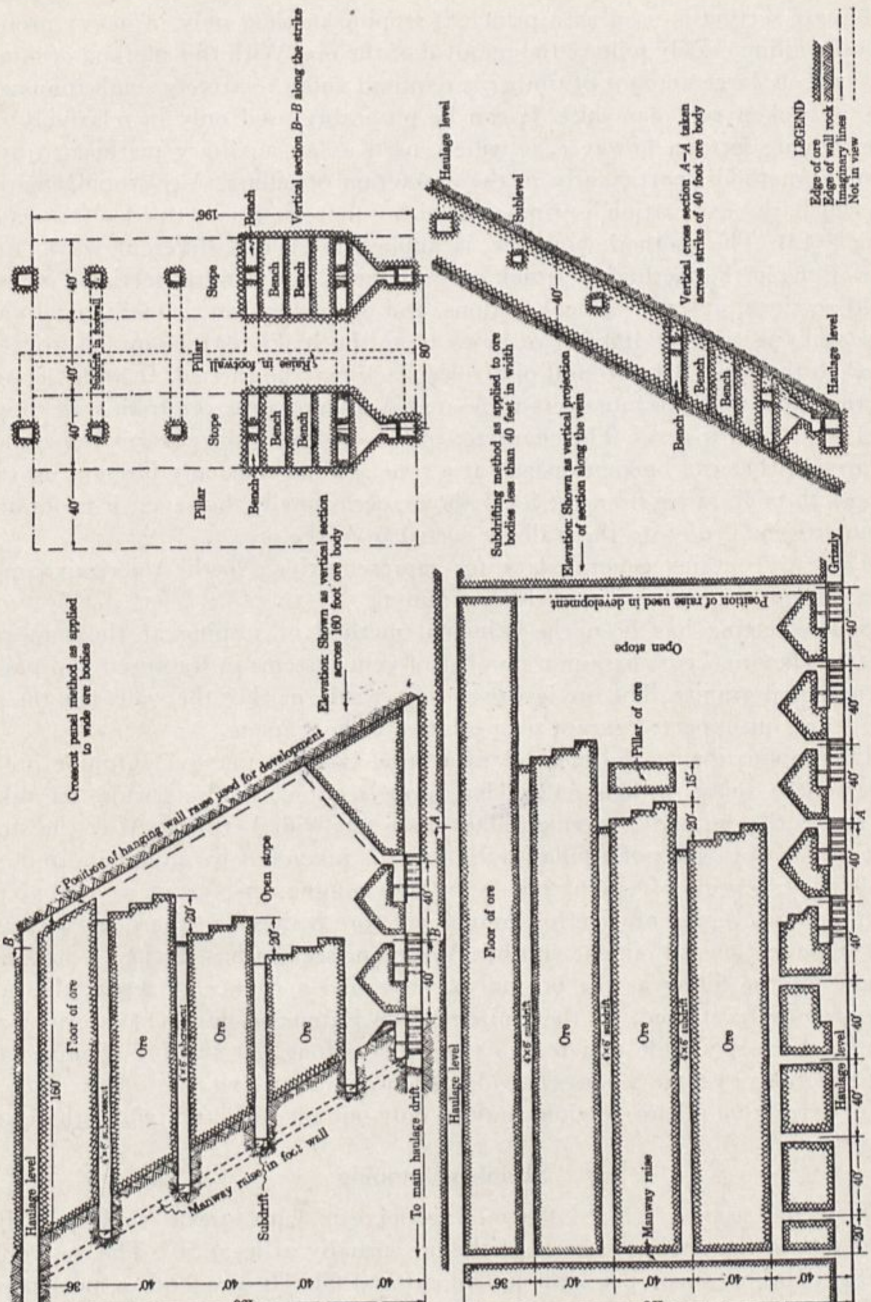

FIGURE 135.—Method of developing and mining sublevel stopes at Burra Burra mine of Tennessee Copper Co., Ducktown, Tennessee.

Square-setting

Square-setting is used as a principal stoping method only in heavy ground; usually filling closely follows the removal of the ore. With this method of mining a relatively large amount of timber is required and a relatively small tonnage of ore is broken per man-shift. It can be profitably used only in relatively rich ore. Square-setting, however, is widely used as an auxiliary method to other stoping methods, particularly in the extraction of pillars. Any stoping method in which the excavation is timbered with square-sets is termed "square-setting" (13). The method, however, is applied in several different ways. Four variations in the method of attack are recognized—horizontal sections, inclined (rill) sections, upward vertical sections, and downward vertical sections. In narrow veins sections of 100 feet or more along the strike may be mined from one level to the next. A horizontal or a rilled back may be carried. In wide deposits sections one to six or more sets wide are taken across the ore from wall to wall and from level to level. The character of the ore and walls governs the amount of ground that can be kept opened at a time. Filling is usually brought into the stopes through raises from the level above; occasionally, however, it is obtained from crosscuts run into the walls or sorted from the ore.

Table 5 contains general data for representative North American copper mines using the square-set method of mining.

Square-setting has been the principal method of stoping at the mines at Butte. The ore occurs here in a number of vein systems in fractured and partly decomposed granite. The ore is structurally weak; neither the walls nor the ore will stand unsupported except over relatively short spans.

The application of the method to a large body of massive sulphide ore in limestone is shown in figure 136. Here stope sections, five sets wide, are taken up across the ore body, leaving pillars three sets wide between. After the stope sections on both sides of a pillar are filled, it is taken out by underhand mining. With the exception of leaving pillars for later mining, the system as used at the Denn mine is representative for mining wide ore bodies by square-setting; usually stope sections adjoin one another. When one section has reached a sufficient height for the filling at the bottom to have had a chance to settle, the next section may be started. At the United Verde Extension mine (14) sections are two to three sets wide and ten to twenty sets long. At the Frood mine (15) stope sections average seven sets wide and twenty sets long.

For extracting pillars, sections may be only one set wide and two or three sets long.

Shrinkage stoping

Shrinkage stoping is used for mining deposits with strong walls and dips greater than the angle of repose of the ore, usually at least 50°. The method is intermediate between open stoping and cut and fill. The ore lends some support to the walls, and shrinkage can be used in some places where open-stope mining would not be practicable. The method cannot be used where sorting in stopes is necessary. Shrinkage stoping appears to be best adapted for mining deposits 6 to 15 feet thick, but ore shoots as thin as 3 feet and as much as 75 feet wide are successfully mined by this method. The stopes reach 200 feet in maximum

Table 5.—*General data for representative North American copper mines using square-set method of mining*

	Anaconda	United Verde Extension	United Verde (underground)	Magma	Copper Queen (Limestone division)	Denn	Colorada	Frood	Matahambre
Location	Butte, Montana	Jerome, Arizona	Jerome, Arizona	Superior, Arizona	Bisbee, Arizona	Bisbee, Arizona	Cananea, Sonora	Sudbury, Ontario	Matahambre, Cuba
Normal daily production of ore (tons):									
Total	10,000	1,200	3,000	830	1,000	350	1,500	[a] 3,000	1,300
By square-setting	8,000	1,200	700	500	550	400	180	[b] 800	400
Total yearly production of ore (tons):									
1929	...	359,000	[b] 800,000	270,000	460,000	106,000	[c] 895,000	[c] 200,000	362,000
1930	...	302,000	[b] 350,000	252,000	280,000	76,000	...	[d] 903,000	369,000
Total yearly production of copper (pounds):									
1929	[e] 297,014,000	54,133,000	[b] 72,000,000	36,517,000	42,559,000	10,700,000	[c] 58,827,000	[f] 92,630,000	31,500,000
1930	[g] 197,233,000	38,883,000	[b] 30,000,000	31,559,000	29,106,000	9,000,000	[c] 42,425,000	[b] 140,288,000	34,109,000
Total production of ore to end of 1930........tons	...	2,700,000	...	2,380,000	...	[h] 228,000	[i] 21,000,000	[c] 26,700,000	...
Total production of copper to end of 1930..pounds	[j] 10,100,000,000	628,000,000	[k] 2,050,000,000	282,000,000	[l] 2,530,000,000	[h] 25,200,000	[m] 1,133,400,000	[c] 990,000,000	...
Kind of deposit	Veins in granite	Sulphide lenses	Massive sulphides	Vein in diabase	Replacement deposits in limestone	Replacement deposits in limestone	Pipe in quartz porphyry	Deposit in shear zone	Lenses
Length of ore body........feet	...	500	1,100	1,200–1,500	...	Up to 500	300	5,000	Up to 275
Thickness of ore body........do	4–100	300	300	[n] 25	...	[n] 125	[o] 20–60	40–200	Up to 30
Grade of ore........percent of copper	4.5	7.4	5.0	7.0	4.9	5.5	4	[p] 4.5	4.5
Dip of ore body........degrees	Steep dips predominate	...	60	45–80	...	90	90	65	42–43
Character of walls	Soft to firm	Swelling to firm	Loose to firm	Weak and crushed	Fairly strong	Fairly strong	Strong	Strong	Weak hanging wall
Depth of ore mined........feet	3,600	1,500	3,000	3,000	1,800	2,300	1,500	3,000	1,800
Level interval........do	100, 200	100	150	125, 150	100	100	125	200	100, 130, 150
Spacing of chutes under stopes........do	25–40	22	20–50	15–25	20–50	20–30	30	17½, 22	50
Method of advance of sections	Horizontal and rill.	Vertical	Horizontal and rill	Downward	Vertical and horizontal	Vertical	Vertical	Horizontal	Horizontal
Number of floors open at one time	2	2	1, horizontal; 2, rill stopes	3	...	Varies	2	2	1
Position of sill floor	Top of drift	Top of drift	Top of drift	Floor of drift	...	Top of drift	11 feet above top of drift	30 feet above rail	14 feet above drift

[a] Mine in 1930 being equipped to handle 8,000 tons daily.
[b] Estimate.
[c] Total of all mines of company.
[d] All mines of company, 2,042,000 tons.
[e] Also 8,565,000 ounces of silver; includes custom ore.
[f] Copper content of matte from all mines of company.
[g] Also 5,569,000 ounces of silver; includes custom ore.
[h] 1926 to 1931 inclusive.
[i] 1901 to 1929 inclusive, of all mines of company.
[j] District.
[k] Estimated total of underground and open-cut mines.
[l] All divisions of Copper Queen mine, 1880 to 1930 inclusive.
[m] 1901 to 1930 inclusive, of all mines of company.
[n] Average.
[o] Where square-set.
[p] Also 2.5 percent of nickel and $4 per ton in precious metals.

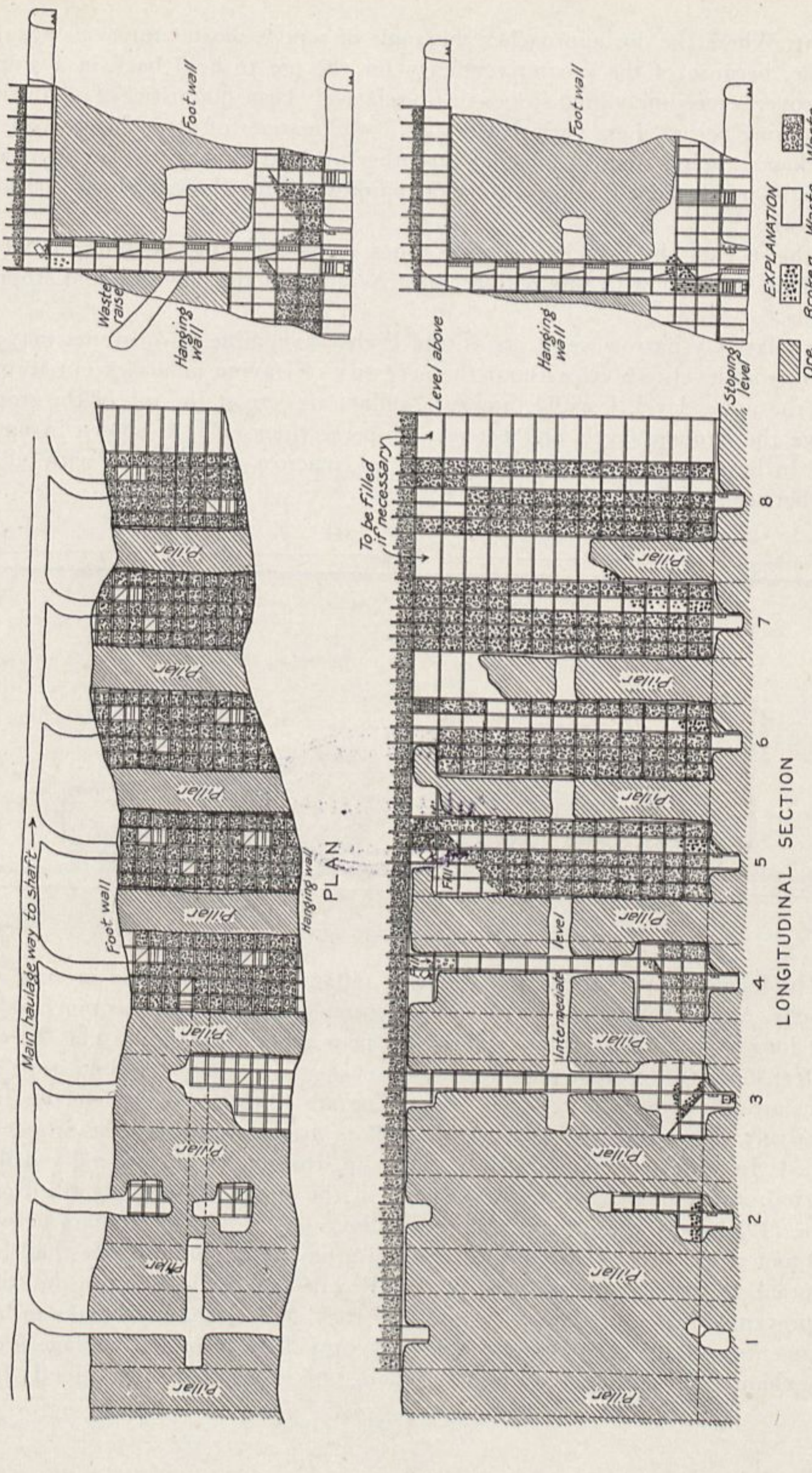

FIGURE 136.—Method of mining at Denn mine, Bisbee district, Arizona.

height. Where the dip approaches the angle of repose shorter intervals are desirable, because of the greater tendency for the ore to hold back in a stope. Moreover, exceedingly high stopes tie up relatively large quantities of ore during the mining period. Less variation occurs in the manner of attacking the ore in shrinkage stoping than in most of the other underground methods. Manways are built up through the broken ore or maintained in pillars at about 100-foot intervals.

Table 6 lists the principal copper mines using shrinkage stoping in North America, together with production data, character of the deposits, and stoping details.

In relatively narrow veins, as at the Eighty-five mine (16), stopes may be taken from level to level without the necessity of leaving pillars except to protect the upper level. Usually, however, pillars are left at the top of the stopes above the haulage levels and between stope sections (17), as shown in figure 137. In large deposits stope sections are taken across the ore body with pillars left between sections.

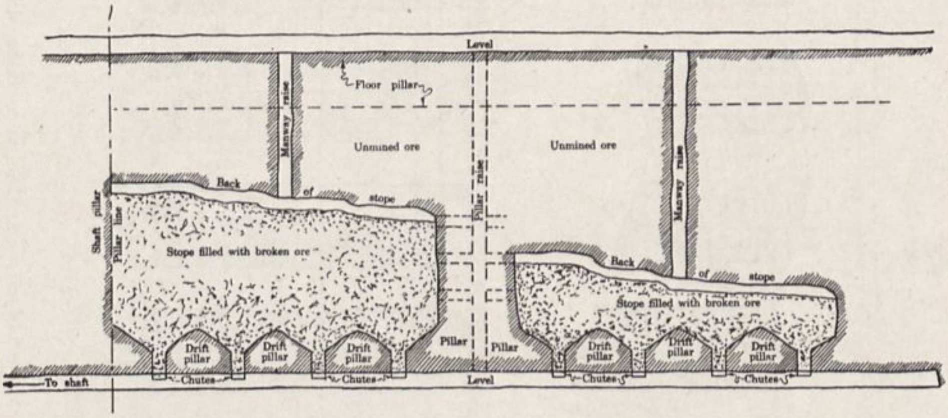

FIGURE 137.—Typical shrinkage stopes in wide veins.

The length of the stopes and width of pillars are governed by ground conditions. At the Walker mine (18) in good ground stopes may be as much as 500 feet long with 50-foot pillars between; in poor ground the stopes may be only 50 feet long with 50-foot pillars. At the Levak mine, where 100-foot stope sections are run across the ore body, the pillars are 40 feet wide. Where the dip is relatively flat, as at the Walker, the pillars are blasted after the stopes are pulled. In wide ore bodies with a steep dip, the pillars are generally drilled, blasted, and pulled with the broken ore in the stope sections. At the Engels mine (19), where the ground was unusually good, the 20-foot pillars between 100-foot stopes were blasted and removed after the adjoining stopes had been emptied. Pillars of lean ore, as at the Isle Royale (20), may be left in the stopes to prevent dilution of the ore by the wall rock. Where the ore breaks in large fragments, grizzly chambers are generally provided above the haulage levels. The chambers are protected by small pillars. Ore is usually drawn directly from

TABLE 6.—*General data for principal North American copper mines using shrinkage methods of mining*

	Walker	Engels	Eighty-five	Verde Central	Kennecott [a]	Isle Royale	Britannia	Creighton	Levak	Garson	Beatson
Location	Spring Garden, California	Engelmine, California	Valedon, New Mexico	Jerome, Arizona	Kennecott, Alaska	Houghton, Michigan	Britannia Beach, British Columbia	Creighton Township, Ontario	Levak, Ontario	Garson, Ontario	Latouche, Alaska
Normal daily production of ore (tons):											
Total	1,600	1,300	300	350	350	1,700	6,000	[b] 5,000	[b] 3,000	[b] 1,600	1,500
By shrinkage	1,600	1,300	225	350	350	1,700	[c] 5,000	[c] 4,500	3,000	1,600	1,500
Grade of ore ... percent of copper	1.7	1.5	2.9	2.6	13	1.0	1.0	[d] 4.6	...	...	1.3
Total yearly production of ore (tons):											
1929	458,000	395,000	59,000	[e] 93,000	137,000	515,000	1,920,000	1,177,000	369,000	246,000	453,000
1930	519,000	[f] 177,000	81,000	[e] 93,000	86,000	510,000	2,152,000	862,000	(g)	278,000	445,000
Total yearly production of copper (pounds):											
1929	15,032,000	11,000,000	[c] 3,000,000	4,335,000	[c] 30,000,000	10,864,000	41,972,000	...	...	...	[c] 11,000,000
1930	15,776,000	[f] 4,073,000	[c] 4,000,000	4,280,000	[c] 24,000,000	10,659,000	44,294,000	...	...	...	[c] 9,500,000
Total production of ore to end of 1930 ... tons	[c] 2,750,000	4,693,000	[c] 1,400,000	186,000	...	[h] 12,849,000	122,150,000	[b] 18,000,000	...	...	[c] 6,000,000
Total production of copper to end of 1930 ... pounds	[c] 105,000,000	159,500,000	...	8,600,000	[c] 925,000,000	235,000,000	418,000,000	(i)	(i)	(i)	[c] 200,000,000
Kind of deposit	Shoots in shear zone	Shoots in shear zone	Vein	Vein	Replacement	Bedded	Shoots in shear zone	Shoots in shear zone	Shoots in shear zone	Shoots in shear zone	Shoots in shear zone
Length of ore body ... feet	200–1,000	830	1,600	Varies	150–1,000	...	300–800	500–1,000	Up to 700	Up to 700	800
Width of ore body ... do	[j] 15	[k] 100	[j] 5	Varies	Up to 100	[j] 9	10–250	50–300	Up to 400	Up to 100	[k] 340
Dip of ore body ... degrees	55–75	80	80	80–90	40–90	56	65–70	45	35–55	55	60–70
Depth of ore mined ... feet	...	2,000	2,000	1,930	...	[l] 5,000	...	2,530	700	1,400	...
Level interval ... do	150	200	150	150	150, 200	[l] 100	200	120	120	100 and 200	...
Spacing of chutes under stopes ... do	50	30	10	25	25–35	18	33 1/3	15	16 by 50	...	34 by 40
Length of stopes ... do	50–500	90–120	100	100	[j] 560	...	300	Up to 250	Up to 400	Up to 100	70–270
Methods of advance or attack	Flat back	...	Stepped back	Stepped back	...	...	Stepped back	Flat back	Flat back	Flat back	Stations in raises

[a] Including Mother Lode.
[b] Tonnage hoisted; considerable waste is removed by sorting in rock house.
[c] Approximate estimate.
[d] Also 5.8 percent nickel (grade of all ores smelted in 1929).
[e] Started January, 1929; closed October, 1930.
[f] Closed July, 1930.
[g] Not operated in 1930.
[h] 1901 to 1930.
[i] Total for company in square-set table.
[j] Average.
[k] Maximum.
[l] On incline.

the stope into cars, but at the Britannia mine (21) it is dropped through gathering raises to a haulage level 200 feet below. At the Creighton mine (22) capping follows the broken ore down as the stopes are drawn.

Cut and fill stoping

In a cut and fill method of stoping relatively thin slices are taken successively from the lower surface of a block of ore; after the broken ore from one slice is removed, the space it occupied is filled with waste material before mining the next slice. Casual support by stulls or cribs may be used to hold up weak sections of the back until they are ready to be blasted.

The method is used under conditions intermediate between those suitable to shrinkage stoping on one hand and square-setting on the other. Through variations the cut and fill method merges into shrinkage stoping, open stoping, or square-setting. The method is flexible in that if heavy ground should be encountered it can be changed readily to square-setting. Should the walls of stopes prove stronger than was expected, a number of cuts may be taken before filling, which would be in effect a semishrinkage method.

Where the cut and fill method is applied to wide ore bodies, it is a common practice to mine out regular sections across the ore body between pillars, which are later stoped by square-setting or top slicing.

Cut and fill stoping can be divided into two general classes—horizontal cut and fill and inclined cut and fill, or rill method (23). In the former the back and filling are kept practically horizontal. In the latter the back and filling are maintained parallel to each other and usually at the angle of repose of the waste material used for filling.

The principal copper mines in North America using the cut and fill method of mining, together with production data, character of the deposit, and stoping data, are set forth in table 7.

The method as applied at the United Verde mine (24) is shown in figure 138. Floors are usually built on top of the filling to receive the broken ore; at the Pilares mine (25), however, the ore is shot down on the leveled and packed waste. At the Matahambre mine (26) chute raises are started on 50-foot intervals; a manway is taken up alongside every third chute. An inclined retreating cut and fill method is used at the Champion mine (27). Sublevels provide three working faces between levels. The ore is shoveled into cars at the toe of the stopes. At the Frood mine (15) a system similar to the one at the United Verde is used. Stopes 45 feet wide are laid across the ore body, with 35-foot pillars between. At the Campbell mine (28) pairs of contiguous stopes, each 45 feet wide, with 45-foot pillars between pairs, are laid out across the ore body. At the Colorada mine (29) cut and fill stopes are 30 feet wide and 50 to 160 feet long, with 40- to 50-foot pillars between, and the pillars are mined by top slicing. A rill stope and pillar system is used at the Magma mine (30), as shown in figure 139. The pillars are mined underhand, as in the system used at the Denn (fig. 136).

TABLE 7.—*General data for representative North American copper mines using cut and fill method of mining*

	Pilares	Matahambre	Champion	United Verde (underground mine)	Frood	Campbell (Calumet & Arizona)	Colorada	Magma
Location	Pilares, Sonora	Matahambre, Cuba	Painesdale, Michigan	Jerome, Arizona	Sudbury, Ontario	Lowell, Arizona	Cananea, Sonora	Superior, Arizona
Normal daily production of ore (tons):								
Total	3,000	1,300	1,500	3,000	[a]3,000	900	1,500	830
By cut and fill	2,300	900	1,500	2,000	[b]2,200	[c]900	600	330
Total yearly production of ore (tons):								
1929	835,000	362,000	447,000	[b]800,000	200,000	[d]578,000	[e]525,000	270,000
1930	646,000	369,000	[b]450,000	[b]350,000	[f]903,000	[d]415,000	....	252,000
Total yearly production of copper (pounds):								
1929	....	31,500,000	20,661,000	[b]72,000,000	[f]92,630,000	[d]55,586,000	[f]58,827,000	36,517,000
1930	....	34,109,000	20,000,000	[b]30,000,000	[f]140,288,000	[d]41,345,000	[f]42,425,000	31,559,000
Total production of ore to end of 1930 ... tons	14,650,000	....	16,338,267	....	[f]26,700,000	[g]12,900,000	[h]22,000,000	2,380,000
Total production of copper to end of 1930 ... pounds	800,000,000	....	532,384,832	[i]2,050,000,000	[f]990,000,000	[g]1,250,000,000	[h]1,133,400,000	282,000,000
Kind of deposit	Tabular	Lenses	Bedded	Massive sulphides	Deposits in shear zone	Massive sulphides	Pipe in quartz porphyry	Vein in diabase
Length of ore body ... feet	Irregular	Up to 275	8,000	1,100	5,000	500	300	1,200–1,500
Width of ore body ... do.	Irregular	Up to 30	[j]17	300	40–200	50–250	200	[j]25
Grade of ore . percent of copper	3	4.5	[k]2.25	5	4.5	[d]5	4	7
Dip of ore body ... degrees	90	42–45	70	60	65	25–90	90	45–80
Character of walls	Weak	Hanging, weak	Hanging, weak	Weak to strong	Strong	Strong	Strong	Weak and crushed
Depth of ore mined ... feet	1,900	1,800	4,000	3,000	3,000	2,300	1,500	3,000
Level interval ... do.	100, 133	100,130, 150	[l]94	150	200	[m]100	125	[m]125, 150
Spacing of chutes under stopes ... do.	30	50	200	16½ or 22	22 or 27½	10	40	1 to a section
Width of sections ... do.	Width of ore body	Width of ore body	Width of lode	30–160	45	45–50	30	16
Length of sections ... do.	Length of ore body	Length of ore body	....	60–200	Width of ore body	Width of ore body	50–160	15–60

Where stopes silled	At level or 20 feet above	14 feet above level	At level	21–25 feet above level	30 feet above level	10 feet above level	11 or 22 feet above level	At level
Inclined or horizontal cuts	Both	Horizontal	Both	Horizontal	Horizontal	Inclined	Horizontal	Inclined
Height of cuts ... feet	8	6–7	$3\frac{1}{2}$–4	7	7	12	11	7

[a] In 1930; mine being equipped to produce 8,000 tons daily.
[b] Estimate.
[c] No pillars mined in 1929 or 1930.
[d] Total Calumet & Arizona mine.
[e] Estimated; total all mines 895,000 tons.
[f] All mines of company.
[g] Total Calumet & Arizona mine to end of 1930.
[h] All mines of company, 1901 to 1930.
[i] Estimated total underground and open-cut mines.
[j] Average.
[k] Recovery.
[l] 100 feet on dip.
[m] Alternate levels used for hauling.

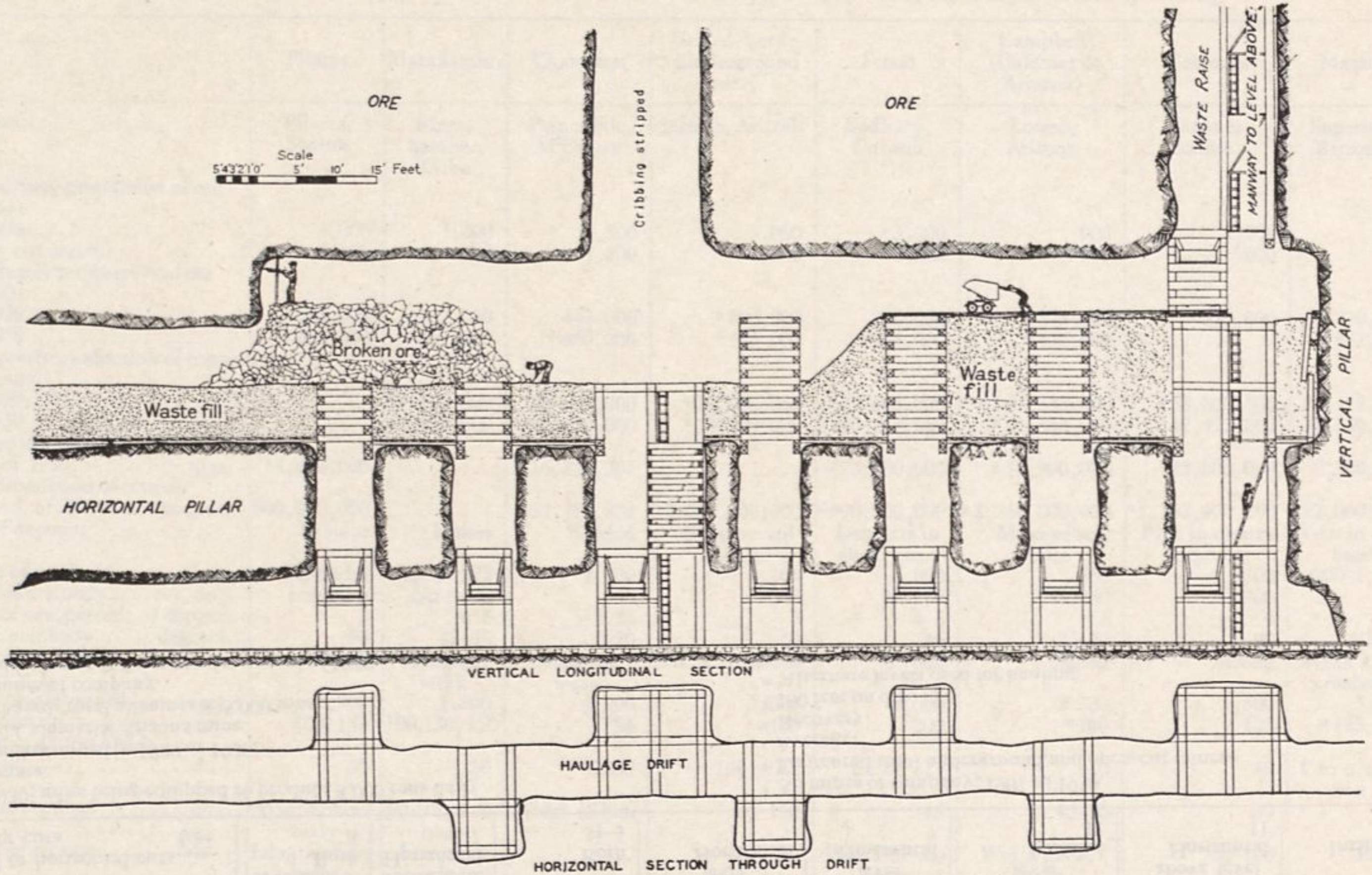

FIGURE 138.—Typical cut and fill stope, United Verde mine, Jerome, Arizona.

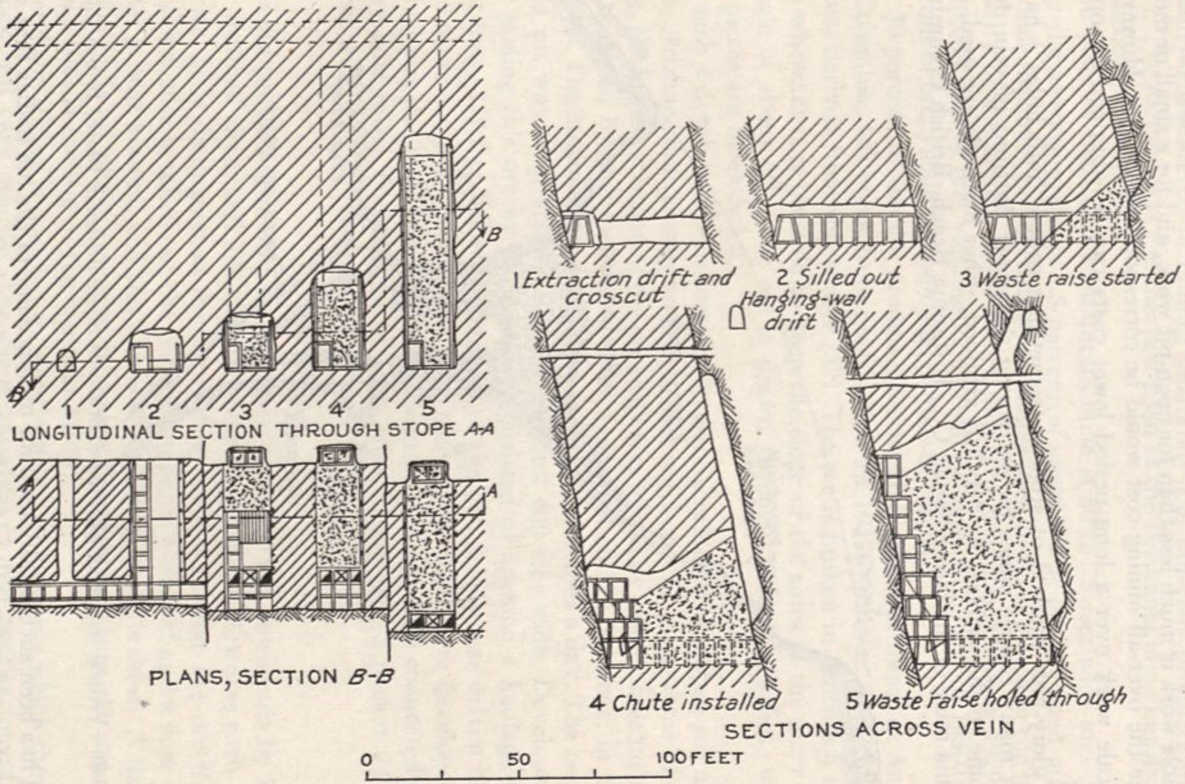

FIGURE 139.—Rill stopes, Magma mine, Superior, Arizona.

Glory hole

The choice between a glory hole and an open pit is usually decided by the scale of operations and the size of the deposit. The cost of equipping a mine for glory-hole work is much less than for open-pit work, and for a small or moderate tonnage the over-all mining cost would be correspondingly lower. However, for large-scale work over a long period lower costs can be obtained by open-cut mining.

The glory-hole method of stoping (sometimes called "mill holes") has been used at many copper mines for extracting the upper portions of vein deposits that come to the surface. As depth is attained, other methods are used. At the Britannia mine of the Howe Sound Co., Britannia Beach, British Columbia, the

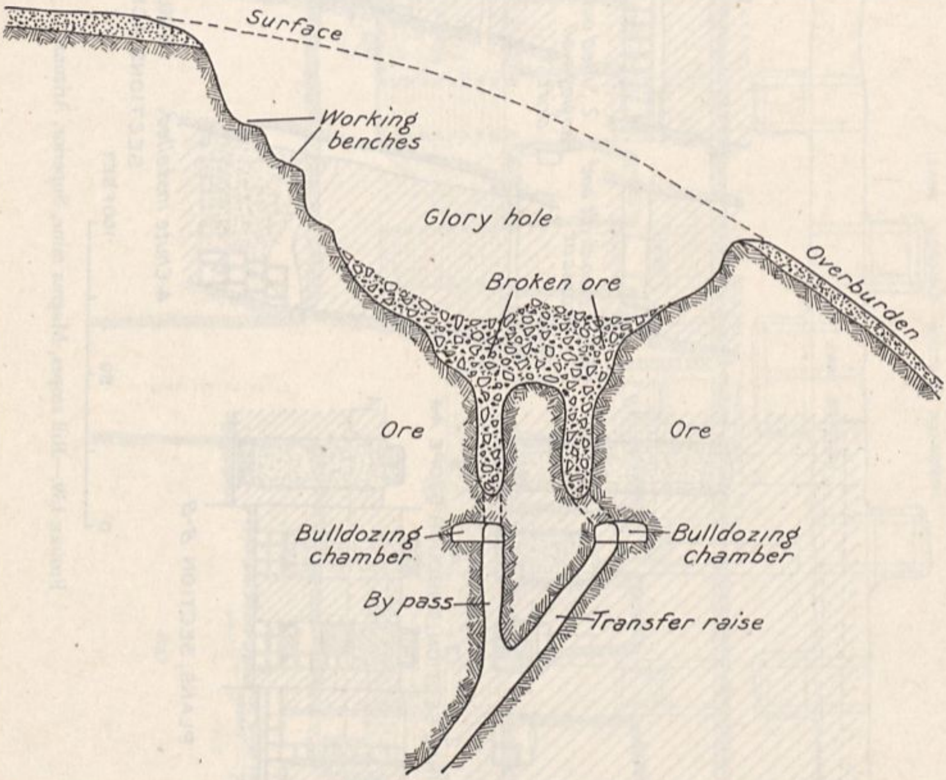

FIGURE 140.—Vertical section of glory hole, Britannia mine, Britannia Beach, British Columbia.

method has been successfully used for mining some of the ore bodies that extend to the surface. (See fig. 140.) It is the principal method used at the relatively new Copper Mountain mine and has been much used at the Hidden Creek mine, both belonging to the Granby Consolidated Mining, Smelting & Power Co., Ltd., in British Columbia.

In the United States the main application of the method to copper mining has been at the Sacramento Hill mine of the Copper Queen branch of the Phelps Dodge Corporation, at Bisbee, Arizona. The method was tried in the lower pit of the United Verde open-cut mine for mining the ore after the overburden had been removed by power shovels but was not successful, mainly on account of the difficulty encountered in mining separately the different products in the mine (31). The method was the cheapest used at the Britannia mine but did not permit selective mining (21).

The ore body of the Copper Mountain mine is 50 to 75 feet wide and 2,700 feet long; the average grade is 1.5 percent of copper. The ore is mined mainly by glory-hole methods, but shrinkage stoping is used in some places in the mine. The capacity of the mine is 3,000 tons a day. The production during 1929 was about 920,000 tons of ore, yielding 22,540,000 pounds of copper; in 1930 it was 700,000 tons of ore, yielding 15,490,000 pounds of copper.

About 30 percent of the ore produced at the Hidden Creek mine, at Anyox, British Columbia, has come from glory holes. In 1932, however, only 5 to 10 percent was derived from this source (32). The ore is broken in benches 8 to 10 feet high wherever it is possible to keep the slope of the sides of the glory hole at an angle of about 45°. The ore is drawn through 18-inch grizzlies, where all large pieces are block-holed.

When such a depth had been attained in the Sacramento Hill open-cut mine, at Bisbee, Arizona, that transportation of the ore from the pit became unduly expensive, the lower extension of the ore body was mined by a glory-hole method. The ore obtained by this method in 1929 amounted to 574,000 tons; in 1930, 304,000 tons. The maximum production was about 2,500 tons a day. The bottom of the old pit was oval, about 450 feet long and 400 feet wide. Development work for mining this ore by glory-holing consisted of opening a haulage level 2,000 feet long, 239 feet below the bottom of the pit. A loop was driven under the pit to serve six glory holes. Later five more glory holes were developed. A grizzly level was put in 135 feet below the bottom of the pit and connected with each glory-hole raise. The bottom of each raise constituted a pocket 24 feet long, 8 feet wide, and 45 feet high.

Top slicing

Top slicing consists of mining an ore body from the top downward by horizontal or inclined slices and allowing the capping to follow down as each slice is taken out. It is distinguished from a caving method in that the ore is not caved. As each slice is taken out the resulting space is timbered and a floor laid. The timber is next blasted, and this allows the capping to settle down. A timber mat is soon built up which prevents the waste above mixing with the ore. The floor of one slice is the top of the one next below.

In general top slicing is confined to fairly wide ore bodies over which the wall or cap rock will cave readily. The main variation in the application of the method is in the manner of cutting the slices—horizontal or inclined. In top slicing, as in caving, a relatively large amount of preparatory work is necessary before stoping can begin. Under usual conditions the daily output for each stope is relatively small, making a considerable number of working places necessary for a large output. Top slicing has been used extensively in copper mines; in 1930, however, comparatively little copper was being produced by this method. During the last few years top slicing has been used mainly for extracting pillars between cut and fill stopes at Cananea, for mining a few ore bodies at Bisbee, and for taking out caved pillars over cut and fill stopes at the United Verde mine. The method is also used in the older mines at Cananea for mining sill pillars at the bottoms of completed stopes.

The pillars between the cut and fill stopes at Cananea are 40 to 50 feet wide and 60 to 100 feet long. Ultimately about 60 percent of the main portion of the ore body will be removed by this system (29). The top-slice stopes are partly developed by the work done preparatory to mining the cut and fill stopes. Drifts have been run along the center lines of the pillars, and raises put up to the top of the ore. In the newer work one central raise is used. A subdrift is run on the center line one or two floors below the active slice. From this sublevel short finger raises are put up to the mining floor. The broken ore falls or is shoveled through these raises onto the floor of the sublevel, where it is pulled by a scraper to a single, central transfer raise.

Leaching in place

Leaching in place consists of percolating leaching solutions through unmined ore. Usually the ore to which this method is applied has been fractured by caving or settling and is of too low grade to be removed and treated economically. The leaching solutions usually consist of mine-drainage water, but acidified creek water may be used. They are collected in workings below the ore; the copper is precipitated on scrap iron in tanks.

Leaching copper from ore in place has been carried on more systematically and on a larger scale at the mine of the Ohio Copper Co., at Bingham, Utah, than elsewhere on the continent (33). Leaching operations began here in 1922. During 1926 the output was 4,964,000 pounds; in 1929, 2,215,178 pounds. The production naturally decreased each year operations were continued.

Ore in old stopes and old fills is leached at the Copper Queen mine, Bisbee, Arizona. In 1929 about 1,000,000 pounds and in 1930 about 600,000 pounds of copper was obtained by leaching underground at the Holbrook plant of the Copper Queen. Part of this copper, however, was obtained from the regular mine-drainage water. A substantial quantity of copper was also obtained during these years by leaching in place in the Junction mine, now a part of the Copper Queen group.

At Cananea, Mexico, underground leaching began in 1923. By 1929 about 2,000,000 pounds of copper was produced annually in this manner, at a cost of slightly over 4 cents a pound. The material leached is old stope filling, low-grade ore in abandoned shrinkage stopes, and the more or less crushed and caved ground surrounding and overlying worked-out top-slice stopes and other caved areas.

Copper-mining costs

Conditions vary so greatly at copper mines that relative mining costs can seldom be given on a strictly comparable basis. Moreover, very few companies figure unit costs in the same manner.

A host of factors influence mining costs, the most important being the mining method used, scale of operations, natural underground conditions, and the efficiency of labor and management. Other factors that have a bearing on costs are prices of supplies and power, modernity of operations, climate, topography, and political restrictions.

Mining costs at representative mines

Open cut.—Direct costs of mining at four open-cut mines are shown in table 8. Variations in cost are due principally to differences in conditions existing at the mines. Where the rock is hard to break, drilling and blasting costs are higher, and, in addition, owing to the coarseness of the broken material, the capacity of the power shovels is less than in material that breaks easily. Haulage costs are governed mainly by the topography of the deposit. Management plays a part in supplying the most economical equipment to perform each task.

TABLE 8.—*Direct mining costs at open-cut copper mines*

	Utah Copper[a]	New Cornelia[b]	Chino[c]	United Verde[d]
Year	1928	1930	1929	1928
Ore mined ... tons	16,558,500	2,376,764	2,621,340	731,488
Costs per ton:				
Drilling	$0.0272	$0.070	$0.02106	$0.139
Blasting	(e)	(e)	.02748	(e)
Shovel operation	.0188	.049	.03604	.077
Transportation	.0536	.066	.10794	.086
Miscellaneous	.0177	.025	.01432	...
Total mining	.1173	.210	.20684	.302
Explosives	.0151	.025	.02126	[f].031
Power	.0034	.004	[g].00517	[g].005
Fuel	.0074	.030	...	...
Labor	[h].0378	.104	...	[f].139
Supervision	.0058	.021	...	...
Total supplies	...	.081	...	[f].092
Ore mined per man-shift ... tons	[i]67.9	42.2	...	[f]32.6
Explosives ... pounds per ton	[i]0.105	0.17	...	[f]0.195
Power ... kilowatt-hours per ton	[j]0.79	[k]0.56	[g]0.04	...

[a] Ore mining only. (See U. S. Bur. Mines Information Circ. 6412.)
[b] Figures cover all material. (See U. S. Bur. Mines Information Circ. 6666.)
[c] Figures for ore mining with electric shovels only. (See U. S. Bur. Mines Information Circ. 6412.)
[d] Open-pit mine; ore mining only except as noted. (See U. S. Bur. Mines Information Circ. 6248.)
[e] Included with drilling.
[f] Total material.
[g] Shovel operation only.
[h] Operating labor only.
[i] October, 1929.
[j] For loading, haulage, and air compression, October, 1929.
[k] For air compression and lighting.

Undercut block caving.—Direct costs at three representative mines at which the ore is mined by the undercut block-caving method are shown in table 9. So many variables exist at each mine that direct comparisons of the total costs are not practicable. The principal factor governing costs is the selection of practices best suited to the conditions in each ore body.

Open stopes, cut and fill, and shrinkage.—Direct mining costs at representative North American copper mines using open stopes, cut and fill, and shrinkage stoping are shown in table 10.

Square-setting.—Cost data at five representative copper mines where square-setting is used are given in table 11.

TABLE 9.—*Mining costs at four copper mines using block-caving method*

	Morenci	Ray	Inspiration	Miami
Period	1928	1928	1928	1925–29
Ore mined .... tons	1,483,984	3,243,159	4,897,646	[a]4,139,074
Copper in ore .... pounds per ton	35	21.3	18.3	11.4
Ore per man in stopes .... tons	62.76	115.61	...	...
Ore per man underground .... do	11.84	12.13	13.1	27
Ore per man on pay roll .... do	10.45	10.83	...	...
Explosive per ton .... pounds	0.19	0.139	...	0.223
Timber per ton .... board feet	0.25	1.88	...	1.045
Power per ton .... kilowatt-hours	...	...	...	1.9
Mining costs per ton:				
Development	$0.142	$0.104	$0.211	$0.100
Stoping	.129	.243	.208	.136
Haulage	...	.091	[b].144	.053
Hoisting	...	.020	...	.033
General underground	...	.057	.012	.032
Engineering and sampling	...	...	...	.014
Mine surface	[c].045	...	.008	.020
Mine accident	...	...	...	.011
General	...	.162	...	...
Supervision	.040	...	...	...
	[d].356	[e].677	[e].583	[f].399
Per pound of copper	.010	.033	.032	.035

[a] Annual average, October 1, 1925, to September 30, 1929; total ore, 16,556,296 tons.
[b] Includes hoisting.
[c] Compressed air, steel, water, and drill expense.
[d] Extraction cost only.
[e] Partial underground cost.
[f] Total mining cost.

Relative stoping costs per ton of ore at the Pilares mine in 1931 with different mining methods were, for square-set, $1.62; top slice, $1.55; horizontal cut and fill, $1.07; rill cut and fill, $0.91; shrinkage, $0.64. Square-setting and top slicing cost $2.87 per ton at the Copper Queen mine in 1930. The total mining cost at the Denn mine, 1927 to 1931, was $6.01 a ton; all the ore was mined by square-setting.

Glory hole.—The cost of glory-hole mining at the Copper Queen mine from June 1929 to March 1931 is shown in table 12. No other data on costs of copper mining by this method are available.

General costs per ton of ore and per pound of copper

Table 13 shows the mining, milling, general, and total costs per ton of ore and per pound of copper at selected mines. The data are taken chiefly from company annual reports; some production figures and costs per ton have been taken from Mineral Resources and Bureau of Mines Information Circulars on mining and milling methods and costs. The costs per pound for mining, milling, and general expenses are calculated except for the Miami mine.

Depreciation and interest are usually not calculated as operating costs but are added as separate items to the cost per pound of producing copper; the same is often true of income taxes. Depletion is another proper charge, amounting at some mines to 6 cents a pound, but is rarely shown in income statements and is excluded from the costs shown in table 13. It is customary to credit the cost per pound with the gold and silver recovered in the ore; miscellaneous revenues are also credited. No uniform method of accounting is followed by the mining companies, and the costs shown in table 13 are not comparable except as qualified by the footnotes.

TABLE 10.—*Direct mining costs at representative copper mines using open-stope, cut and fill, and shrinkage methods of stoping*

	Michigan copper mines[a]	Tennessee Copper Co.[b]	Ducktown Chemical Co.[c]	Colorada	Pilares	Magma	Champion	Matahambre	Engels[d]	Beatson[e]	Eighty-five[f]	Verde Central[g]	Colorada[h]
Method used	Open stope	Open stope	Open stope	Cut and fill	Cut and fill	Cut and fill	Cut and fill	Cut and fill	Shrinkage	Shrinkage	Shrinkage	Shrinkage	Shrinkage
Period	1927	1928	1928	[i]1929	1929	1928	[j]1930	1928	1928	1922–26	1928–29	1929–30	1931
Ore mined, tons	1,151,557	473,292	108,519	262,278	835,036	263,094	193,597	364,746	303,301	2,239,821	7,332	139,203	74,307
Cost per ton of ore:													
Development	$0.379	$0.229	$0.355	$0.561	$0.399	$0.736	$0.490	$0.711	$0.479	$0.290	$1.00	....	....
Stoping	[k].920	.332	.890	1.203	1.370	2.849	1.163	1.267	.760	.366	1.75	$1.661	$0.464
Haulage	.303	.386	.369	[l].166	[l].370	[l].616	[l].552	[l].388	[l].438	[l].137	.82	[l].580	....
Hoisting	.176	....	....	....	....	....	....	....	....	....	.33	....	....
Pumping	.048	....	....	....	....	....	.133	....	....	....	.66	....	....
Surface	.031	.043	.060	.233	.211	.130	.112	.019	(m)	....	.31	.033	....
General	....	.145	.154	.278	.250	1.166	.078	.184	(m)	....	.62	.111	....
	1.554	1.135	1.828	2.441	2.600	5.497	2.528	2.569	1.677	.793	5.49	[n]2.385	.464
Labor	.934	.654	1.082	1.102	1.374	3.343	1.649	1.433	1.028	.347	2.47	1.268	[o].183
Supervision	....	.090	.087	.171	.219	.311	.107	.155	.070	....	....	.126	....
Supplies	.527	.356	.443	1.098	.952	1.646	.192	.894	.390	.446	.92	.915	[p].220
Power	.093	.035	.216	.070	.055	.197	.580	.087	.189	....	1.10	.076	.061
	1.554	1.135	1.828	2.441	2.600	5.497	2.528	2.569	1.677	.793	[n]4.49	[n]2.385	[q].464

[a] Long, narrow open stope supported by narrow pillars (U. S. Bur. Mines Bull. 306).
[b] U. S. Bur. Mines Information Circ. 6149.
[c] U. S. Bur. Mines Information Circ. 6397.
[d] U. S. Bur. Mines Information Circ. 6260.
[e] Am. Inst. Min. Eng. Trans., vol. 76, pp. 11–52, 1928.
[f] U. S. Bur. Mines Information Circ. 6413.
[g] U. S. Bur. Mines Information Circ. 6464.
[h] Information from C. E. Weed, general manager, Cananea Consolidated Copper Co.
[i] First 6 months.
[j] Last 5 months.
[k] Includes tramming, compressor, and drill expense.
[l] Includes hoisting.
[m] Not included.
[n] Excludes development.
[o] Includes supervision.
[p] Includes breaking and handling waste fill.
[q] Stoping only.

TABLE 11.—*Cost data at representative mines using the square-set method*

	Anaconda	Old Dominion	United Verde	Copper Queen	United Verde Extension
Year	....	1928	1929	[a] 1930	1928
Ore mined......tons	....	350,661	....	725,409	275,212
Ore per man-shift (tons):					
Stopes	5.05	[b] 5.70	[b] 2.45	6.8	4.8
Total mining	1.82	[c] 1.89	....	....	2.0
Timber......board feet per ton	22.05	[d] 4.8	[b] 12.52	14.5	16.8
Explosives (pounds per ton):					
Stopes	....	[e] 0.28	[b] 0.60	0.67	0.39
Total mining	1.07	....	1.05	....	....
Ore per foot of development...tons	[f] 18.0 [g] 14.2	....	28.7	14	....
Cost per ton:					
Stopes	....	....	....	$2.17	$1.83
Total mining	....	....	....	....	4.29

[a] Last 6 months.
[b] Square-set stopes only.
[c] All methods including development.
[d] Stoping only.
[e] All methods excluding development.
[f] 1927.
[g] 1926.

TABLE 12.—*Cost per ton of glory-hole mining at the Copper Queen mine, June, 1929, to March, 1931*

[Information supplied by J. P. Hodgson, manager, Copper Queen branch, Phelps Dodge Corporation. Ore from glory holes, 1,357,441 dry tons; through grizzlies, 1,415,617 dry tons]

	Glory hole	Grizzlies	Total
Stoping:			
Labor	$0.033	$0.056	$0.089
Supplies	.008	.013	.021
Drills and tools	.012	.016	.028
Timber	....	.001	.001
Explosives	.034	.018	.052
	.087	.104	.191
Exploration and development	....	....	.017
Underground repairs	....	....	.014
Tramming	....	....	.082
Hoisting	....	....	.116
Drainage	....	....	.029
Sanitation	....	....	.005
Ventilation	....	....	.003
Sampling and assaying	....	....	.015
Mine-department expense	....	....	.045
			.517
Proportion of general departments	....	....	.027
Transportation to concentrator	....	....	.064
			.608

Tons per man-shift:
- Glory holes.............120.11
- Grizzlies............... 98.39
- Total................... 54.09

TABLE 13.—*Mining, milling, and general cost per ton of ore and per pound of copper at selected mines*

Mine	Year	Ore treated (tons)	Copper produced (pounds)	Mining cost		Milling cost		General cost		Total cost	
				Per ton	Per pound	Per ton	Per pound	Per ton	Per pound	Per ton	Per pound
Utah Copper	1929	17,724,000	[a]296,626,000	$0.412	$0.0247	$0.366	$0.0219			[b]$0.868	[c]$0.0665
Do	1930	9,552,000	[a]161,139,000	.504	.0299	.461	.0273			[b]1.069	[c].0847
Do	1931	8,148,000	[a]142,695,000	.396	.0226	.393	.0224			[b].90	[c].0699
Chino	1929	3,973,000	[d]85,000,000	[e].314		.59					[fg].0953
Do	1930	2,514,000	[d]56,000,000	[e].334		.545					[fh].1085
Do	1931	2,620,000	[d]51,000,000	[i].267		.360					[fi].0868
Copper Flat	1929	[d]3,800,000	[d]60,000,000	[k].242		.421					(l)
Do	1930	[d]2,100,000	[d]48,000,000	[k].282		.458					(l)
Do	1931	[m]2,238,000	[d]38,000,000	[n].266		.443					(l)
Ruth	1929	[d]1,400,000	[d]48,000,000	[k].95		.421					(l)
Do	1930	[d]700,000	[d]24,000,000	[k].936		.458					(l)
Do	1931	(m)	[d]18,000,000	[n].748		.442					(l)
Ray	1929	3,609,000	[d]66,000,000	[o].828		.394					(l)
Do	1930	2,327,000	[d]36,000,000	[o].680		.382					(l)
Do	1931	1,287,000	[d]24,000,000	[p].753		.400					(l)
Inspiration	1929	5,774,000	107,307,000								[q].1113
Do	1930	3,054,000	65,607,000								[q].0967
Do	1931	2,621,000	61,368,000								[q].0843
Miami	1929	5,018,000	58,841,000	.423	.036	.359	.031	$0.152	$0.013	[r].934	[s].1174
Do	1930	6,125,000	67,125,000	.396	.036	.297	.027	.139	.013	[r].832	[s].1088
Do	1931	4,439,000	50,573,000	.357	.031	.277	.024	.183	.016	[r].818	[s].0993
Consolidated Copper Mines	1930	1,115,000	32,612,000	1.535	.052						[t].1107
Do	1931		15,076,000		.053						[t].1097
Calumet & Hecla	1929	[u]3,129,000	[u]90,319,000								[v].1143
Do	1930	[u]2,934,000	[u]87,898,000								[v].1056
Do	1931	[u]2,066,000	[u]72,367,000								[v].0977
Mohawk	1929	620,000	20,043,000							1.859	.0732
Do	1930	472,000	13,308,000							1.949	.0872
Do	1931	444,000	13,100,000							1.650	.0704
Quincy	1929	208,000	4,459,000								.1997
Isle Royale	1929	515,000	10,864,000							2.67	[v].1401
Do	1930	510,000	10,659,000							2.44	[v].1297
Do	1931	353,000	7,731,000							2.24	[v].1148
Champion	1929	447,000	20,661,000								[v].1176
Do	1930		20,000,000	[w]2.528	[w].055						[v].1160
Do	1931	[x]405,000	[x]17,721,000								[v].0975

All Michigan mines[y]	1929	5,154,000	152,900,000	...	.082	...	[z].025	...	[aa].026	...	[bb].1369
Do.	1930	5,100,000	151,500,000	...	.073	...	[z].023	...	[aa].025	...	[bb].1251
Granby (all units)	1929	2,490,000	60,855,000	...	...	...	...	...	...	...	[cc].1061
Do.	1930	[d]2,200,000	46,800,000	...	...	...	...	...	...	...	[cc].0980
Do.	1931	1,578,000	36,512,000	...	...	...	...	...	...	...	[cc].0682

[a] Includes copper from precipitating plant.
[b] Excluding depreciation and Federal taxes.
[c] Excluding Federal taxes, but including depreciation and all general expenses; also credits as follows: 1929, $0.0145; 1930, $0.0123; 1931, $0.0102; for gold, silver, and miscellaneous earnings.
[d] Estimated.
[e] Ore mining only; excludes depreciation and taxes, also prepaid stripping charge of $0.45.
[f] Average for Chino, Copper Flat, Ruth, and Ray; excludes Federal taxes; includes depreciation and general expenses; also includes credit for gold and silver and miscellaneous earnings.
[g] $0.0888 before Federal taxes and depreciation.
[h] $0.0959 before depreciation.
[i] Excludes depreciation, taxes, and $0.35 prepaid stripping charge.
[j] $0.0813 before depreciation.
[k] Excludes depreciation and taxes and $0.40 prepaid stripping and development charge.
[l] See Chino figure.
[m] Includes Ruth production.
[n] Excludes depreciation and taxes and $0.30 prepaid stripping and development charge.
[o] Excludes depreciation and taxes and $0.15 prepaid development.
[p] Excludes depreciation and taxes and $0.065 prepaid development.
[q] Includes depreciation; excludes depletion and Federal taxes.
[r] To concentrate on board cars Miami; excludes depreciation.
[s] Excludes depreciation and depletion. Cost in concentrate on board cars at Miami: 1929, $0.0797; 1930, $0.0759; 1931, $0.0718.
[t] Includes depreciation and Federal taxes; also credit for gold and silver (about $0.01).
[u] Excluding reclamation plants.
[v] Excludes depreciation and depletion.
[w] Underground cost for 194,000 tons hoisted last 5 months of 1930.
[x] Includes Baltic mine.
[y] State mine appraiser's report as quoted in Mineral Resources; excludes reclamation plants.
[z] Includes transportation to mill, concentration, smelting, and refining.
[aa] Includes depreciation and local taxes.
[bb] Includes selling expense, new construction and income taxes.
[cc] Excludes depreciation, depletion, and income taxes; includes credit for gold and silver (about $0.007).

TABLE 13.—*Mining, milling, and general cost per ton of ore and per pound of copper at selected mines*—Continued

Mine	Year	Ore treated (tons)	Copper produced (pounds)	Mining cost		Milling cost		General cost		Total cost	
				Per ton	Per pound	Per ton	Per pound	Per ton	Per pound	Per ton	Per pound
Noranda	1929	422,000	51,625,000	...	...	...	...	...	...	...	[dd].1001
Do	1930	849,000	76,142,000	...	...	...	...	...	...	...	[dd].0716
Do	1931	1,012,000	62,010,000	...	...	...	...	...	...	...	[dd].0435
Flin Flon	[ee] 1931	1,091,000	[ff] 31,069,000	...	...	...	...	...	...	[gg] 3.13	[hh].0887
Sherritt-Gordon	[ii] 1931	...	14,718,000	...	...	...	...	...	...	...	[jj].0805
United Verde Extension	1929	...	[kk] 64,112,000	(ll)	.025	...	...	...	...	...	[mm].0842
Do	1930	...	[kk] 45,567,000	...	.028	...	...	...	...	...	[mm].0833
Do	1931	183,000	24,591,000	...	.027	...	...	...	...	...	[nn].0658
Shattuck-Denn	1929	129,000	12,736,000	...	...	...	...	...	...	...	[oo].1260
Do	[pp] 1930	[d] 86,000	9,948,000	...	...	...	...	...	...	...	[oo].1206
Walker	1929	458,000	13,958,000	[qq] 1.782	.059	[rr].776	.025	...	...	[ss] 2.558	[tt].1080
Do	1930	519,000	14,655,000	[qq] 1.820	.064	[rr].687	.024	...	...	[ss] 2.507	[tt].1054
Engels	1929	395,000	11,000,000	[uu] 2.565	.092	[vv].660	.024	[ww].516	.019	3.742	[xx].1799
Do	[yy] 1930	177,000	4,073,000	[zz] 1.891	.082	[vv].767	.033	[ww] 1.050	.046	3.708	[aaa].2007
Verde Central	1929	93,000	4,335,000	...	...	...	...	...	...	...	[bbb].1693
Mother Lode	1929	57,200	[ccc] 12,243,000	[ddd] 4.15	...	...	...	...	...	...	[eee].0673
Do	1930	27,500	[ccc] 9,647,000	[ddd] 12.53	...	...	...	...	...	...	[eee].1152
Calumet & Arizona [fff]	1929	...	130,487,000	...	...	...	...	...	...	...	[ggg].0984
Do	1930	...	88,840,000	...	...	...	...	...	...	...	[ggg].1127
Cananea	1929	895,000	58,827,000	...	...	...	...	...	...	...	[hhh].0660
Do	1930	...	42,425,000	...	...	...	...	...	...	...	[hhh].1041
Do	1931	...	41,873,000	...	...	...	...	...	...	...	[hhh].0513
Magma	1929	270,000	[iii] 38,235,000	...	...	[jjj].934	[jjj].007	...	...	...	[jjj].1029
Do	1930	252,000	[lll] 31,884,000	5.46	.043	...	...	...	...	...	[kkk].0877
Do	1931	231,862	28,840,000	...	...	...	...	...	...	...	[kkk].0787

[d] Estimated.
[dd] Includes general expenses, taxes, depreciation, and credit for gold, silver, and other income as follows: 1929, $0.041; 1930, $0.041; 1931, $0.090; excludes depletion.
[ee] Started August, 1930.
[ff] Also 35,056,000 pounds of zinc.
[gg] Includes all operating, administrative, and overhead costs for mining, milling, smelting, and electrolytic zinc refining.
[hh] Includes depreciation, interest and all expenses, also $0.093 (estimated), credit for zinc, gold, and silver.
[ii] Nine months; started April, 1931.
[jj] Includes depreciation, prepaid development, also $0.008 credit for gold and silver.
[kk] Includes about 5,000,000 pounds custom ore.

[ll] Mining cost in 1928 for 275,000 tons was $4.286 per ton and about $0.026 per pound.
[mm] Excludes depletion; includes depreciation and taxes, also credit for gold, silver, and miscellaneous income.
[nn] Excludes item of $0.036 for Federal taxes and losses sustained.
[oo] Includes depreciation and interest, also credit for gold and silver of $0.020 in 1929 and $0.016 in 1930.
[pp] Stoping ceased Nov. 1, 1930.
[qq] Stoping cost $1.245 in 1929, $1.267 in 1930.
[rr] Includes aerial tramway operation of $0.906 per ton of concentrate, equivalent to $0.065 per ton of ore milled.
[ss] Operating cost.
[tt] Excludes depreciation, depletion, and interest; includes credit (about $0.03) for gold and silver.
[uu] Includes $1.436 development and exploration and $0.080 electric haulage of ore to mill.
[vv] Includes loading of concentrates.
[ww] To concentrate on board cars; includes depreciation, general and fixed expense, taxes, and insurance.
[xx] Includes freight and smelting (about $0.054), also credit for gold and silver (about $0.008).
[yy] Mine shut down July, 1930.
[zz] Includes $0.652 for development and exploration and $0.086 for electric haulage of ore to mill.
[aaa] Includes freight and smelting (about $0.046), also credit for gold and silver (about $0.006).
[bbb] Excludes $0.0129 charged to depreciation and amortization, also excludes $0.002 credit for gold and silver.
[ccc] Shipped to smelter.
[ddd] Mining and milling.
[eee] Excludes depreciation and depletion; includes general expense and taxes, also $0.004 credit for silver.
[fff] Includes New Cornelia.
[ggg] Includes depreciation and taxes, also credit for gold and silver (about $0.018).
[hhh] Includes depreciation and taxes, also credit for gold and silver (about $0.007).
[iii] Includes 1,719,000 pounds from purchased ore.
[jjj] First 6 months.
[kkk] Includes depreciation, general expenses, and taxes, also credit for gold and silver ($0.025 in 1929, $0.018 in 1930, and $0.0156 in 1931).
[lll] Includes 326,000 pounds from purchased ore.

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