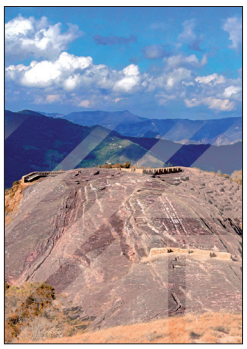

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Formal and iconographic analysis and interpretation of the most damaged petroglyphs

Formalna i ikonograficzna analiza najbardziej zniszczonych petroglifów oraz ich interpretacja

Outline of the study

The state of preservation of the petroglyphs on the sacred rock of Samaipata is very differentiated: some are still well visible, while others have hardly any traces remaining. However, some of them are still identifiable thanks to modern documentation technologies, laser scanning, structured light scanning, digital photogrammetry, and advanced digital analysis of images and 3D models.

This reason that some petroglyphs are badly conserved is the combined effect of at least three factors:

1. Differential erosion of rock surface. Certain parts of the rock are more exposed to environmental effects such as insolation, wind erosion, moisture impact, and lichen action. This results in a differentiated degree of erosion of particular petroglyphs, depending on their location on the rock.

2. Anthropic factors. This category includes at least two types of actions:

– The superposition of representations, especially in the Inca period. This even means some previous representations were erased and replaced with others, according to the ceremonial or religious requirements of the particular time period.

– The activities of visitors "decorating" the original engravings with contemporary inscriptions, drawings, etc. Thanks to the establishment of the Archaeological Research Centre in Samaipata and the imposed strict protection of the petroglyphs, such activities ended practically in the eighties of the last century.

3. Relative chronology of particular petroglyphs: the oldest ones, mainly due to environmental factors, show a more advanced state of deterioration than the most recent ones. Obviously, the process of differentiated wear is also related to the conditions listed in the first (and second) point, however, generally, we can tentatively accept that the oldest phases of artistic activity on the rock correspond to the most deteriorated petroglyphs.

We decided to dedicate a study to five petroglyphs at different stages of deterioration. The study involved three steps:

– Searching for visualisation methods that would allow the original form of today's indecipherable petroglyphs to be identified;

– Identifying the original iconographic program of individual engravings;

– Searching for possible stylistic and formal analogies in order to fit the iconographic program into the broader context of rock art in this part of South America.

This is a preliminary study and is not intended to constitute an exhaustive analysis of the possible affiliates of the petroglyphs. Aside from this, it should be stressed that the aforementioned deterioration processes have erased several details essential for any attempt at advanced comparative analysis on a stylistic and chronological level. The basis of the analysis, or rather, of the critical com-

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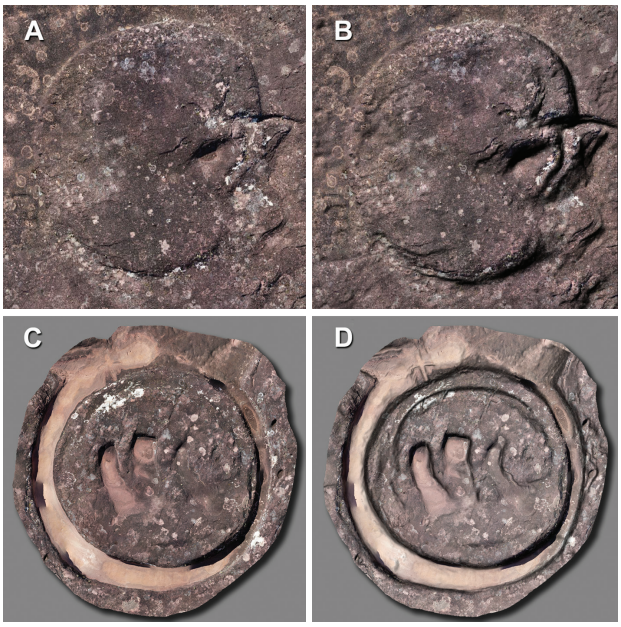

Fig. 1. Examples of orthoimages
from short-range digital photogrammetry:
A – RGB orthoimage of "Puma(?)" petroglyph from sector W05;
B – same RGB orthoimage with unidirectional hill
shading superimposed;
C – RGB orthoimage of "Jaguar(?)" petroglyph from sector W06;
D – same RGB orthoimage with unidirectional hill
shading superimposed (elaborated by J. Kościuk)

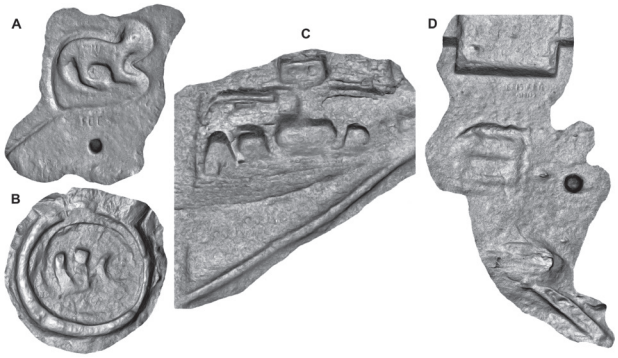

Fig. 2. Examples of structured light 3D scanning.
Views of 3D models without texture but
with unidirectional hill shading:
A – "Puma(?)" petroglyph from sector W09;
B – "Jaguar(?)" petroglyph from sector W06;
C – "Double Puma(?)" petroglyph from sector S14;
D – "Snake-catching Animal" and "Meandering Snake" petroglyphs
from sector W10
(elaborated by M. Pakowska)

mentary presented below, is mainly the works of the interdisciplinary team that included anthropologists, archaeologists, architects, specialists on rock art, and specialists on remote sensing.

The authors of this paper did nothing more than compare these two approaches, contextualised with some recent publications on the general theme of rock art in the Bolivian East.

Methods of documenting and visualising petroglyphs at different stages of erosion

In most cases, it is difficult to separate documentation methods from methods of visualising the results of documentation processes, as the same method can be applied for both purposes. The methods used for these purposes in this particular project were as follows:

– Short-range digital photogrammetry;
– Structured light 3D scanning;
– Hill shading algorithms;
– DTM and hypsometry;
– 3D printing;
– Virtual polynomial texture mapping (vPTM) and virtual reflectance transformation imaging (vRTI) as the most reliable sources for interpretation attempts.

These are detailed in the following sections of this article.

Short-range digital photogrammetry

Photogrammetry is becoming an increasingly common tool in cultural heritage documentation [1], [2]. It was used in this project both for the documentation of the entire Samaipata rock and detailed documentation of the most important petroglyphs[1].

However, with all its advantages (ease of data collection, simplicity of processing, accuracy, and resolution), photogrammetry has some drawbacks. For this project, a major disadvantage was its dependence on local field conditions. Images of some highly eroded petroglyphs that were photographed in diffused light (weather conditions were not always optimal) do not sufficiently reflect all the nuances of the surface (Fig. 1A). In more favourable lighting conditions and with larger relative differences in the depth of the relief, images are admittedly more satisfactory, but due to unidirectional lighting, still, not all details are clear (Fig. 1B). In this situation, texture-free renderings from 3D models preferably illuminated from the opposite direction were applied on orthoimages obtained from photogrammetry. Adding two such images definitely improved the readability (Figs. 1B, D).

Structured light 3D scanning

Despite the fact that virtually no structured light scanners are particularly suitable for outdoor use, scanning the most important petroglyphs produced very informative data.

The very detailed and accurate registration of the current condition of the petroglyphs has in itself great documentation value. The obtained data also brought a lot of additional information to the process of interpretation of individual petroglyphs. Particularly useful was to turn off the texture when rendering 3D mesh models (Figs. 2A–D). Even the simplest rendering algorithms with unidirectional lighting revealed many new details that were invisible in the field.

[1] Cf. B. Ćmielewski, I. Wilczyńska, C. Patrzałek, J. Kościuk, *Digital close-range photogrammetry of El Fuerte de Samaipata*, in this issue of "Architectus".

Hill shading algorithms

A similar situation was observed when analysing photogrammetric data. Textured 3D models were practically just as indecipherable as the petroglyphs in the field. The colourful patches of lichens and moss, as well as the rock itself at various stages of its erosion, distracted the eyes and hindered the interpretation of shapes even in favourable lighting conditions (Figs. 3A, C).

Turning off colour information on the rendered 3D model and using a hill shading algorithm definitely improved the clarity of shapes (Figs. 3B, D).

This method of documentation and analysis was used as the first stage of research where the existence of blurred petroglyph traces was suspected. It did not always give conclusive results, but many doubts were eliminated in this way. Where suspicions were confirmed, the more sophisticated analysis techniques of vPTM and vRTI were used.

DTM and hypsometry

Another method of visualising photogrammetry results was the use of hypsometry to colour DTM models. In addition, unidirectional hill shading (Figs. 4A, C) was ap-

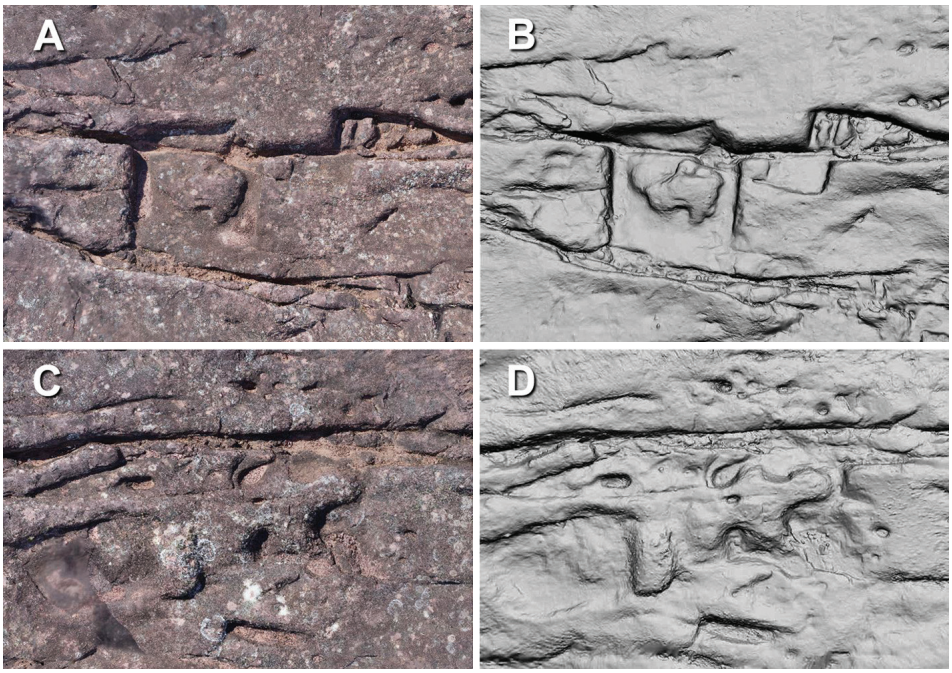

Fig. 3. Examples of the hill shading algorithm applied to photogrammetric projects: A – unrecognised petroglyph(?) from sector N10 (RGB orthoimage); B – same fragment as 3D model without texture but with hill shading applied; C – unrecognised petroglyph(?) from sector N10 (RGB orthoimage); D – same fragment as 3D model without texture but with hill shading applied (elaborated by J. Kościuk)

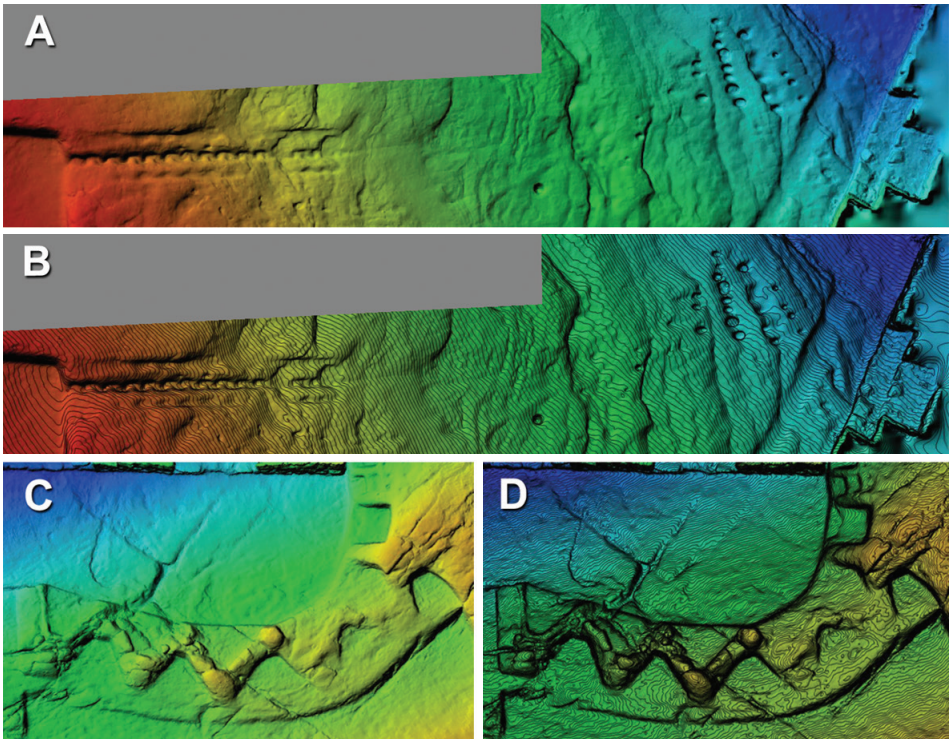

Fig. 4. Hypsometric mapping based on DTM: A – "Triple Snakes" petroglyph from sector N10 (unidirectional hill shading applied); B – same image with contour lines added; C – triangular niches (Snake petroglyph?) from sector S29 (unidirectional hill shading applied); D – same image with contour lines added (elaborated by J. Kościuk)

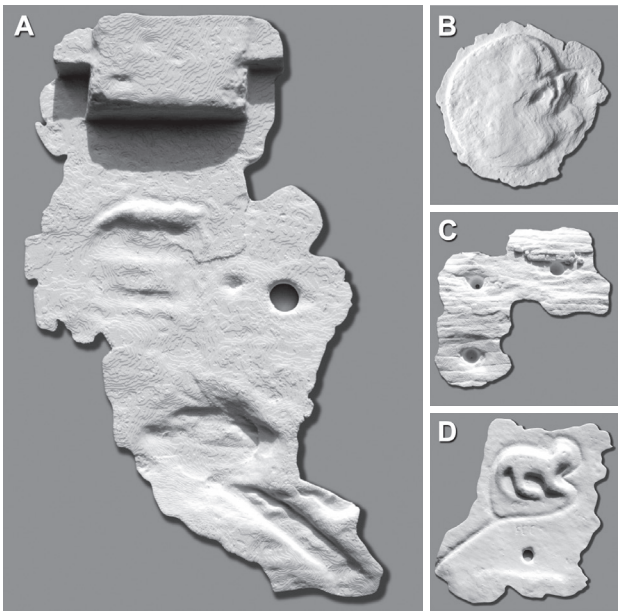

Fig. 5. Examples of scaled-down petroglyphs copied on a 3D printer:
A – "Snake-catching Animal" and "Meandering Snake" petroglyphs from sector W10;
B – "Puma(?)" petroglyph from sector W05;
C – post-holes for *quincha* wall in sector N02;
D – "Puma(?)" petroglyph from sector W09
(3D models and 3D printing: M. Pakowska; photo by J. Kościuk)

plied to the DTM to emphasise the relief. All these functions are the standard options of AgiSoft PhotoScan Pro – the software used in this project.

Visualisation by colouring relative and absolute height relations (hypsometry) did not bring breakthrough results, but allowed better understanding of the spatial shape of the analysed rock surface. Application of contour lines (another option available in AgiSoft PhotoScan Pro) additionally made the images clearer (Figs. 4B, D).

3D printing

In recent years, 3D printing has found its way into applications in cultural heritage research [3], [4]. In this project, it was primarily used to check how truly physical 3D prints of virtual 3D models can imitate original petroglyphs.

As the Samaipata rock will continue to erode, one should take into account that at some point, even the petroglyphs that are still decipherable today will disappear completely. Will only photographs, drawings, and descriptions be left as the only testimony? When using digital photogrammetry and 3D scanning with structured light, we get virtual copies of the petroglyphs, but they are only available to a small group of researchers with the appropriate software and will be rather difficult for a wider audience to see. So what is the chance that they can be made available to a wider audience in the form of exact physical copies?

To check this possibility, four 3D prints of selected petroglyphs were made in a reduced scale. Due to the limitations of the maximum dimensions of the printout that fits our printers, depending on the size of the petroglyph, the scales 1:20 (Figs. 5B, D) or 1:25 (Fig. 5A) were used. In our opinion, even prints in such a reduced scale well reflect the characteristic features of an individual engraving. With the progress of 3D printing technology, printing at scales closer to the originals and even on a 1:1 scale will be possible. To check whether such 3D prints would render all the details visible, a small fragment of the scanned surface, with characteristic fissures and numerous fragments of rock material already separated from its base, was selected for printing (Fig. 5C). On even a 1:10 printout, all these details became clearly visible. This proves that 3D printing has great potential in mapping reality and that 3D scanning documentation is accurate and has a high resolution.

vPTM and vRTI as the most reliable method for interpretation attempts

vPTM and its variant vRTI turned out to be the methods that provided the most reliable data for the interpretation of blurred petroglyphs[2].

In the case of relatively well-preserved carvings (Fig. 6A), vPTM allowed additional details to be captured, or for alternative hypotheses to be checked (Fig. 6B). Using images generated with vPTM technology, it was also easier to interpret some details (Fig. 6C), such as the representation of the face of a mythical creature placed above the heads of two pumas (Fig. 6D). Even in the case of the completely blurred petroglyph of "Crawling Snake" (Fig. 6E), on whose location and shape we have only very scant historical records [5], [6] we could at least indicate its most likely location and outline (Fig. 6F). The vPTM method also allowed the entire petroglyph to be reconstructed (Fig. 6G) and its blurred parts to be virtually restored. It also turned out to be more useful for distinguishing concave and convex relief (Fig. 6H).

The benefits from using the vPTM method in the project were best demonstrated in the case of the petroglyph from sector W10. Small protrusions on the surface of the rock suggested the existence of a figural relief in this place. 3D structured light scanning had revealed that there could be some unclear animal and at least one snake there (Fig. 2D). It was only when twice scaling the virtual 3D model along the *z*-axis and using the vPTM method (Fig. 6I) that it was possible to identify it as a representation of an animal that catches a snake's head with its snout. Another snake is grabbing the tail of the first one (Fig. 6J). Scaling along the *z*-axis a further three times (Fig. 6K) revealed yet another snake (Fig. 6L) emerging from a hole in the rectangular protrusion in the centre of the whole scene[3].

[2] Cf. J. Kościuk, M. Telesińska, M. Nisztuk, M. Pakowska, *Documentation of the most important petroglyphs by structured light scanning and analysis of the most damaged petroglyphs by vPTM and vRTI methods*, in this issue of "Architectus".

[3] J. Kościuk, G. Orefici, M. Ziółkowski, A. Kubicka, R. Muñóz Risolazo, *Description and analysis of El Fuerte de Samaipata in the light of new research, and a proposal of the relative chronology of its main elements*, in this issue of "Architectus".

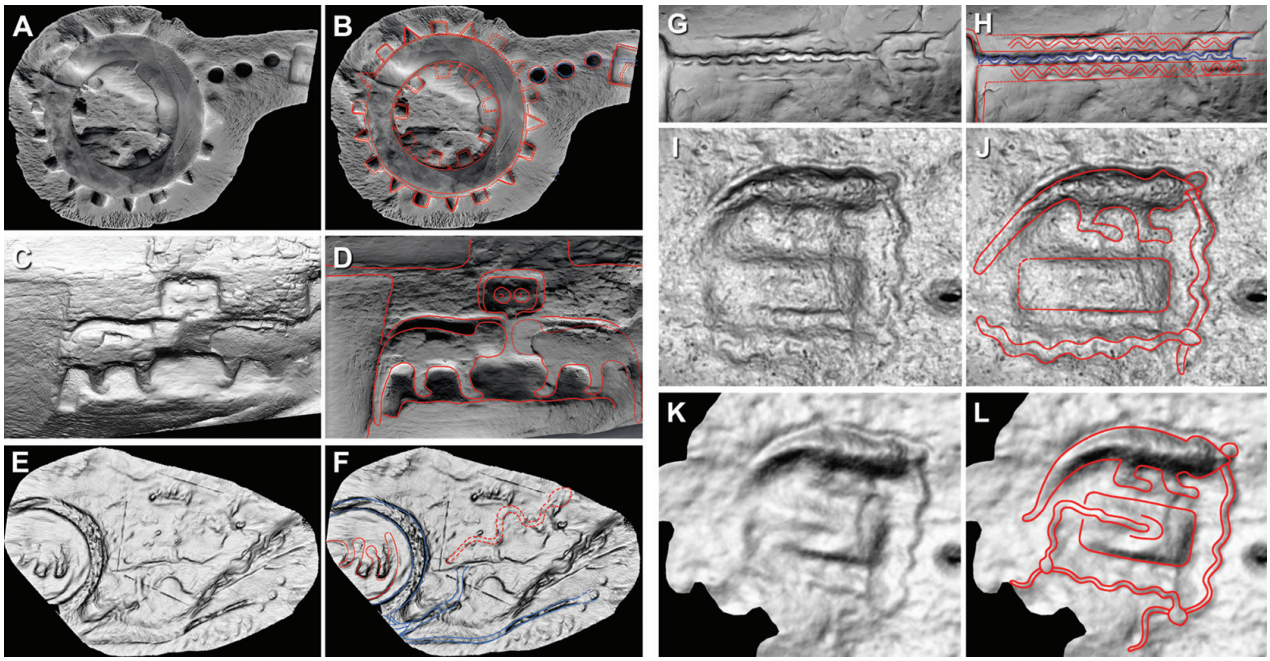

Fig. 6. Examples of 3D virtual models of petroglyphs viewed in a multi-lighting vPTM environment:
A – Altar petroglyph from sector C05; B – interpretation of the same petroglyph;
C – "Double Puma(?)" petroglyph from sector S14; D – interpretation of the same petroglyph;
E – "Crawling Snake" petroglyph from sector W06; F – interpretation of the same petroglyph;
G – "Triple Snake" petroglyph from sector N10; H – interpretation of the same petroglyph;
I – "Snake-catching Animal" petroglyph from sector W10; J – interpretation of the same petroglyph;
K – "Snake-catching Animal" petroglyph from sector W10 after scaling 3-times alongside the *z*-axis;
L – interpretation of the same petroglyph
(elaborated by J. Kościuk)

For obvious reasons, the vPTM method failed when there were no physical traces left of a petroglyph known only from historical sources, so we were dependent only on more or less reliable guesses. This was the case with the relief depicting the rhea.

Formal and iconographic interpretation of petroglyphs

The following description follows the order of the examples of petroglyphs in Figure 6. After this list is exhausted, other rock carvings are discussed.

Petroglyph from sector S14 – "Double Puma(?)"

Engravings suggesting the existence of an image with two eyes between which water flows (Fig. 6D) have analogies in the pre-Columbian art of South America.

The first is a slightly geographically distant sculpture from Lavapatas near San Augustin in Columbia (Fig. 7). Although in this case, the water flows around the face of the depicted character, the analogy of the interaction between the engraved image and the water stream is obvious [7]. The second analogy, much geographically closer and more similar to the case of Samaipata, is the relief from Urco Calca near Calca Calca in the Urubamba Valley in Peru (Fig. 8). Here, the stream of water flows just through the centre of the image of the mythical creature.

Petroglyph from sector W06 – "Crawling Snake"

Using vPTM and vRTI techniques (Fig. 6E), we were able again to identify at most a vague outline of a snake crawling towards the north-west (Fig. 6F).

However, according to some earlier investigators, this petroglyph was interpreted as a representation of a coiled snake – at least, that is how Leo Pucher depicts it on his map of Samaipata rock from 1936 [8]. Given the available evidence, we must reject Pucher's interpretation. Additionally, such representations are not known in the rock art of the investigated region[4] although a representation of a semi-coiled snake appears among the motifs carved in the megalith of Santa Cecilia [9, p. 43, Fig. 10]. However, the traces left on the Samaipata rock seem to correspond to a crawling serpent. The significant deterioration of the image excludes any attempt to determine its stylistic and cultural affiliation, but the motif of the crawling snake is also often present in Inca culture (Figs. 9, 10).

Petroglyph from sector N10 – "Triple Snakes"

Very interesting is also the image of the three parallel serpent-like incisions going in the same direction to give the same movement in the descent of the liquid. However, although the motif of the snake is profusely represented

[4] G. Orefici, personal e-mail communication from August 2019.

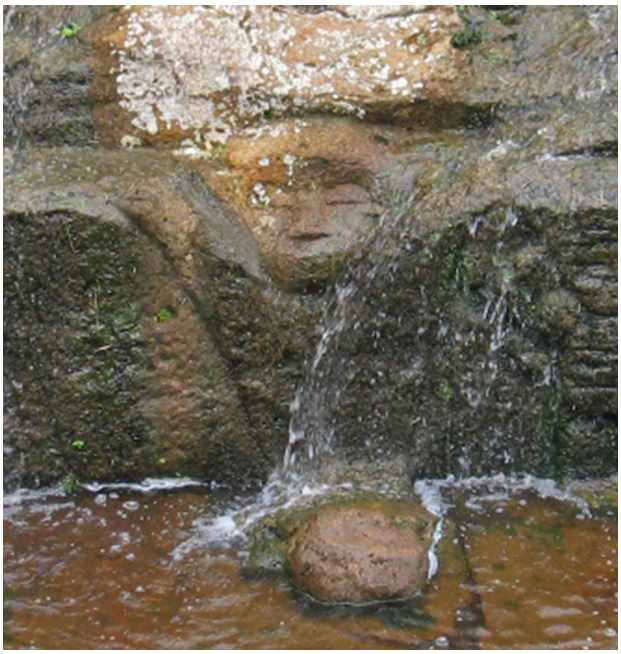

Fig. 7. Detail of the relief from Lavapatas near San Agustin (Columbia) (photo by M. Ziółkowski)

Fig. 8. Detail of the relief from Urco Calca near Calca Calca (Peru) (photo by J. Kościuk)

Fig. 9. Snake relief from Qenco near Cusco (Peru) (photo by J. Kościuk)

Fig. 10. Snake relief from Urco Calca near Calca Calca (Peru) (photo by J. Kościuk)

in rock art (Figs. 9, 10), given the schematic character of the representations, it would be risky to propose specific chronological or cultural analogies.

Petroglyph from sector W10 – "Snake-catching Animal"

This petroglyph has already been briefly discussed above. Considering the fact that the form of this snake-catching animal seems to be different from all other representations of four-legged animals present on the Samaipata Rock, which are all feline, an interpretation may go in the direction of white-nosed coati (lat.: *Nasua narica*; local names: *pizote*, *antoon*, *tejón*), the only similar animal from the area, known as a snake catcher [9]. In addition, if the figure of the main animal had ears, they do not seem typical of feline ears, and the elongated shape of the head is also different to felines. The only problem is that there are no other known examples of a scene of a coati grabbing a snake. Regardless, it is a scene related to the cult of water.

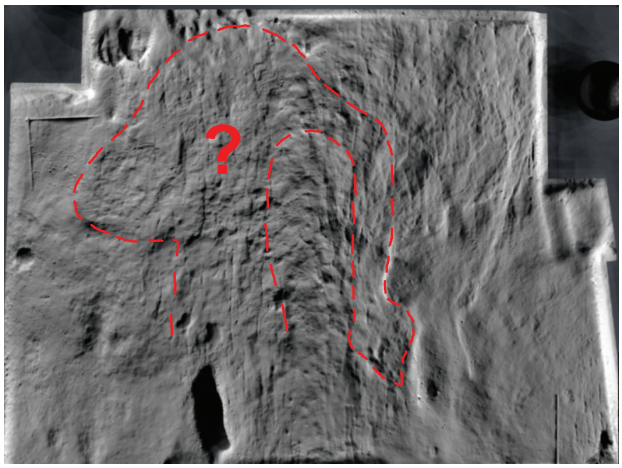

Fig. 11. Rhea (*Ñandú*) petroglyph from sector W09. First interpretation (elaborated by J. Kościuk)

Fig. 12. Rhea (*Ñandú*) petroglyph from sector W09. Corrected interpretation (elaborated by J. Kościuk)

Petroglyph from sector W10 – "Meandering Snake"

This type of representation is quite widespread in the rock art of the Bolivian East [9], but the degree of erosion of the image does not allow any more precise chronological or cultural affiliation to be made.

Petroglyph from sector W05 – "Puma(?)"

Only very weather-beaten traces of this figural petroglyph are extant. Earlier research described it as a representation of a puma or jaguar [5], [6], but today it is difficult to establish the shape of the figure, not to mention determine a particular species. Its reconstruction must be treated with great caution since the surface is highly eroded and additionally disturbed by projecting mosses and lichens. Fragments of the rough rock surface, especially around the north-western edge of the oval, that were detected on the images obtained using the vPTM technique[5] may suggest that the figure has been intentionally recut (and perhaps also erased) by the most recent occupants of the site. This could explain the observation that the proportions of the parts of the body of the animal, in particular the relatively small size of its tail in relation to the rest of the body, are not typical of other representations of felines still visible in the rock. Nevertheless, the identification of this image as a puma remains problematic.

Petroglyph from sector W09 – "Rhea (Ñandú)"

The petroglyph representing the rhea has also probably been intentionally hammered out. Our attempts to reconstruct it using vPTM and vRTI ended only with a general suggestion about the size and orientation of the figure[6].

Although the presence of a representation of a rhea in this part of the rock is confirmed by both d'Orbigny's and Pucher's drawings and indirectly by Frank's early testimony [10], several doubts persist as to the exact shape of the animal. D'Orbigny and Pucher draw a bird with its neck and head raised, although their representations differ in orientation by 180 degrees.

One of interpretations derived from vPTM studies proposed a similarly oriented reconstruction (Fig. 11). However, it is completely different from any similar image in Bolivian rock art. There are no known examples of rheas represented with the neck down. The other reconstruction (Fig. 12), which again is based only on technical observations, seems to be less doubtful. Additionally, the drawings by d'Orbigny and Pucher, although both very schematic, contradict each other. In any case, the rhea is a very important animal in the mythology of different indigenous peoples of the Bolivian East [9].

Petroglyph from sector C05 – "Altar"

The most obvious aspect of this representation is that it seems to correspond to the last phase of the sculpturing of the Samaipata rock in the time of the Incas. It is possible that this petroglyph erased some earlier carvings from the pre-Inca period that surely had great symbolic importance given the prominent character of this part of the rock.

Conclusions

The analysis of the eroded petroglyphs allows them to be linked to fairly common representations in the rock art of the Bolivian East. The supposed image of the coati catching a snake is particularly interesting. However, the degree of deterioration of the petroglyphs and the disappearance of certain diagnostic details makes it difficult to search for specific chronological and cultural affiliations

[5] Cf. J. Kościuk, M. Telesińska, M. Nisztuk, M. Pakowska, *Documentation of the most important petroglyphs by structured light scanning and analysis of the most damaged petroglyphs by vPTM and vRTI methods*, in this issue of "Architectus".

[6] Cf. J. Kościuk, M. Telesińska, M. Nisztuk, M. Pakowska, *Documentation of the most important petroglyphs by structured light scanning and analysis of the most damaged petroglyphs by vPTM and vRTI methods*, in this issue of "Architectus".

and analogies. Incidentally, authors who write about Samaipata seem rather cautious in any complex comparative iconographic analysis with other manifestations of rock art of this area [9], [11], [12].

On the other hand, interpretations of the symbolic and religious aspect of the representations underline the presence of important motifs and figures in the worldviews of some contemporary indigenous peoples: *Mediante la recuperación de mitos orales de pueblos de Tierras Bajas hemos logrado acercarnos un poco a la probable significación de los motivos representados. Queda claro, en base a las referencias aquí presentadas, que motivos como las serpientes se relacionan fuertemente con elementos como el agua, la cultura y la roca, así como las aves semejantes a avestruces o ñandús – piyos en Tierras Bajas – poseen una relación con la noche, el alimento y las estrellas* [9, p. 32].

Samaipata is decidedly anomalous with respect to other relief representations of mythical figures that are stylistically of *selvatic* origin. They are also the oldest in comparison to the altar and other geometric representations. However, we have no elements of comparison with relief figures known in Bolivian rock art in the areas of Cochabamba and Santa Cruz for which Samaipata provides unique examples of rock art. We remain then with the enigma of the origins and cultural affiliations of the first phases of cultural activity of the sacred rock of Samaipata.

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Abstract

This paper presents a study of some of the most deteriorated petroglyphs from the Samaipata Rock, and is the part of the larger research project "Architectural examination and complex documentation of Samaipata (Fuerte de Samaipata/Bolivia)". The study involved the following three steps: 1) Searching for visualisation methods that would allow the original form of today's indecipherable petroglyphs to be identified; 2) Identifying the original iconographic program of individual engravings; 3) Searching for possible stylistic and formal analogies in order to fit the iconographic program into the broader context of rock art in this part of South America.

Due to the amount of material available and its multi-threaded nature, the study does not exhaust the topic, but only, based on some of the most characteristic examples, shows the methodological and methodical aspects of studying such petroglyphs.

Key words: Samaipata, rock art, 3D laser scanning, structured light scanning, digital photogrammetry

Streszczenie

Artykuł przedstawia badania kilku z najbardziej zniszczonych petroglifów z El Fuerte de Samaipata i jest częścią większego projektu „Badania architektoniczne i kompleksowa dokumentacja stanowiska Samaipata (Fuerte de Samaipata/Boliwia) z Listy Światowego Dziedzictwa". Badanie miało trzy fazy: 1) poszukiwanie metod wizualizacji, które pozwoliłyby zidentyfikować oryginalną formę dzisiejszych nieczytelnych petroglifów, 2) określenie oryginalnego programu ikonograficznego poszczególnych rytów, 3) poszukiwanie możliwych analogii stylistycznych i formalnych w celu dopasowania programu ikonograficznego do szerszego kontekstu sztuki naskalnej w tej części Ameryki Południowej.

Ze względu na ilość dostępnego materiału i jego wielowątkowy charakter praca nie wyczerpuje tematu, ale jedynie – w oparciu o niektóre z najbardziej charakterystycznych przykładów – pokazuje metodologiczne i metodyczne aspekty badania silnie zniszczonych i nieczytelnych petroglifów.

Słowa kluczowe: Samaipata, sztuka naskalna, laserowe skanowanie 3D, skanowanie światłem strukturalnym, fotogrametria cyfrowa