

Deciphering of objects: Non-destructive analyses and interpretation of a ceramic object and a pebble in the Museo Nacional de Costa Rica

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Abstract: Two objects believed to have played a role in the metallurgical production of pre-Columbian gold and copper items from Costa Rica underwent archaeometric analysis. A crucible, initially described as pottery, and a peperite pebble consisting of red chert (also commonly termed jaspis) and basalt, which is coated with a yellow, shiny metal—presumably gold—were examined non-destructively using digital microscopy and scanning electron microscopy. The remnants of yellow metal on both objects were analysed for their elemental composition using an energy-dispersive X-ray spectroscopy system attached to the scanning electron microscope to confirm the presence of gold and characterise its composition. Observation of the morphology of the gold led to a decision of whether the objects were of metallurgical or natural origin, revealing that the crucible served a metallurgical purpose, whereas the gold on the pebble was a natural formation rather than originating from use as a metalworking tool.

Keywords: metallurgy; crucible; pebble; jaspis; gold; burnishing; tool; melting; vitrification; scanning electron microscopy; energy-dispersive X-ray spectroscopy; digital microscopy; elemental mapping; element analysis.

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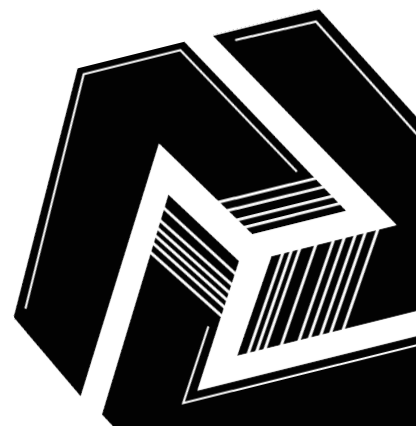
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Descifrando objetos: análisis no destructivos e interpretación de un objeto cerámico y un guijarro en el Museo Nacional de Costa Rica

Resumen: Se sometieron a análisis arqueométricos dos objetos que se cree que desempeñaron un papel en la producción metalúrgica de artículos de oro y cobre precolombinos de Costa Rica. Un crisol, descrito inicialmente como cerámica, y un guijarro de peperita compuesto por chert rojo (también conocido comúnmente como jaspe) y basalto, recubierto de un metal amarillo brillante, presumiblemente oro, fueron examinados de forma no destructiva mediante microscopía digital y microscopía electrónica de barrido. Se analizó la composición elemental de los restos de metal amarillo de ambos objetos para confirmar la presencia de oro y caracterizar su composición con mayor detalle. La observación de la morfología del oro llevó a decidir si los objetos eran de origen metalúrgico o natural, revelando que el crisol tenía una finalidad metalúrgica, mientras que el guijarro era un elemento natural y no una herramienta para trabajar el metal.

Palabras clave: metalurgia; crisol; guijarro; jaspe; oro; bruñido; herramienta; fusión; vitrificación; SEM; microscopía digital; mapeo elemental; análisis elemental.

Introduction¹

A project on “Pre-Columbian gold and copper in Costa Rica”, funded by the Deutsche Forschungsgemeinschaft (DFG) and lasting four years (2023-2026), focused on gold and copper objects, primarily from the Museo Nacional de Costa Rica (MNCR), their metallurgical production and technology, and the exploited mineral resources of gold and copper in Costa Rica (Gassmann et al., 2023). Gold and copper objects were accessible for typological, technological, and archaeometric (analytical) investigation in the museum; the fieldwork was more time-consuming, mainly due to difficult-to-access or private terrain and, due to seasonal conditions, only feasible during three annual field campaigns.

Unlike the mentioned aspects, archaeological findings directly evidencing pre-Columbian metallurgical activity are almost absent in Costa Rica. The reconstruction of smelting technology and the ores used generally requires remains of the smelting process, such as furnace parts, tuyères, crucibles, tools, ore and flux fragments, charcoal and ash deposits, waste products such as slag, and by-products, e.g. matte for smelting of sulphide copper ores. Rebuilding the production technology of finished objects needs crucibles, moulds, tuyères, hearths or forges, tools, unfinished or miscast objects, and lumps of raw or semi-processed metal. In Costa Rica, such evidence is extremely rare, making metallurgical reconstruction very difficult. As part of the project, an approach to understanding the manufacturing techniques used to produce the objects was pursued by examining selected gold and copper objects with a digital microscope. This enabled the reconstruction of various processing steps and techniques (Klein et al., 2025).

Given the widespread lack of such evidence, each discovery attributed to Costa Rica’s metallurgical practices is of great significance. Two findings are discussed here. They serve as excellent examples of how key archaeometric-analytical methods are indisputably crucial for a targeted investigative approach,

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providing unequivocal results. This allows for an assessment of the relevance of the objects within the metallurgical context of Costa Rican gold and copper. The archaeometric-analytical study comprised two non-destructive techniques: a portable digital microscope and a scanning electron microscope (SEM) at the Universidad Nacional de Costa Rica (UNA). Both objects were handled with great care to preserve their integrity and avoid any alteration of their conservation state.

A gold-covered stone from the Cantarero archaeological site

Cantarero (P-35-Ct) is an archaeological settlement with mounds and terrain modifications that is situated on the banks of the Tigre River, one of the main gold-bearing rivers of the Osa Peninsula in southeastern Costa Rica (Corrales Ulloa, 2019; US Geological Survey [USGS], 1987), at an altitude of between 60 and 80 meters above sea level (Figure 1.a.). Archaeological investigations conducted since 2015 have established that the site extended over about 2.5 hectares and comprises at least 15 structures. Most of them are artificial elevations, mounds, and terraces. The mounds have diameters ranging from 8 to 25 meters and heights from 0.5 to 3 meters, with retaining walls constructed from stones sourced from the Tigre River. The settlement's location on an elevated hill, with a view and control of the river, suggests a possible strategic function linked to defense. Other smaller sites without structures have been recorded in the surrounding area and would have been subordinate to Cantarero (Corrales Ulloa, 2019). The pottery collected on the surface and during excavations is associated with the Aguas Buenas period (300 BCE-800 CE), corresponding to the sequence of pre-Columbian occupations in the Diquís Archaeological Subregion (Corrales Ulloa, 2016). Lithic remains are scarce, and only some fragments of metates, polished axes and a stone with grooves, which could have been used as a sharpener for stone tools, were recorded (Corrales Ulloa, 2019).

In Cantarero, ceramic fragments of the Galo Polychrome type have been found, corresponding to the Bagaces period (500-800 CE) of the Gran Nicoya archaeological region. This suggests the existence of regional exchange activities. It is possible that they arrived through Caño Island, where Gran Nicoya ceramics have been documented in significant quantities (Corrales Ulloa, 2019). Three dates were obtained from charcoal samples, with dates ranging from 435 to 880 CE (Corrales Ulloa, 2019). These results position the occupation of Cantarero in the second half of the proposed range for the Aguas Buenas period (300 BCE-800 CE), which appears to be a regional trend observed at other sites of this period with similar structures (Corrales Ulloa, 2016). For this period, which extends to southeastern Costa Rica and western Panama, there is no documented use of gold, even though at the regional level in southern Central America, it was already being used for various ornaments (Bray et al., 2021). However, since Cantarero is situated next to the Tigre River, which carries placer gold, its ancient inhabitants were eventually able to exploit this resource.

In November 2017, based on reports of gold mining activities, or illegal gold extraction at the archaeological site, an inspection was carried out in which soil removal was observed in the vicinity of a secondary creek located in the southern sector of the site, in an area of 20x30 m. The alteration affected the section of a pre-Columbian retaining wall built with river stones, as well as the removal of a large number of ceramic



Figure 1: a. Location of the Cantarero archaeological monument, Osa Peninsula, southeastern Costa Rica. b. Location of the gold-covered stone, Cantarero archaeological monument.

fragments from their original context. In the wall of the removal cut (Figure 1.b.), along with ceramic materials, the presence of a peperite pebble consisting of basalt and red chert (also commonly termed jasper) was observed. When removed, it revealed the surficial presence of golden particles. Due to the unusual nature of the object, it was collected along with some pre-Columbian ceramic fragments for later analysis. Based on its appearance, it was instantly assumed that it could be a burnishing tool and that the surface gold could be abrasion residue from the smoothing process. If this could be confirmed, it would be the first direct evidence of the processing of gold in a site from the Aguas Buenas period.

A crucible without context

The archaeological collection of the MNCR has been assembled since 1887 through voluntary donations, seizures, purchases (when permitted by law), and through authorised research or excavations. This has resulted in a diverse set of materials: some with archaeological context, derived from systematic investigations, and others without context, originating from chance finds or illicit excavations. These differences directly affect the quality of information each artefact can provide. In some cases, contextless pieces were submitted with information about their origin; however, in many others, this information was not provided or simply unknown. Therefore, sometimes the only available data comes from subsequent studies or analyses conducted on the artefacts. One such case corresponds to the artefact identified as MNCR 25648-2 (Figure 2), originally recorded as a monochrome pot. The collection reports ten ceramic containers from Costa

Rica with shapes that may suggest use as crucibles, five without context and five with context. The sites are Liberia, Limón, and three are from Cascabel, and one from Orocú. Cascabel is a site where possible crucibles and objects were found, providing further potential for the investigation of metallurgical activities. The crucibles in the MNCR collection are made of a very white, quite light ceramic and bear traces of burning from being subjected to fire. Five of the ten of the containers were presented in 2025 for examination. They were inspected by eye and with a digital microscope for traces that might indicate metallurgical activity, e.g. vitrified rims or metal (gold) *prills*. In the end, evidence was found for only one of them: object MNCR 25648-2. This object entered the collection without context on May 7, 1980, as part of a voluntary donation made by the renowned collector Carlos Balser, which included a set of 133 pre-Columbian pieces made of metal, bone, stone, and clay, among which the object was later identified as a crucible used for metal smelting. The crucible has a hemispherical shape with an outward-flaring rim, a rough finish, and a whitish colour. Smoke is visible inside due to soot. Its dimensions are 4.8 cm in height, 6.2 cm in diameter, and it weighs 67.83 grams. Although Balser was not formally trained as an archaeologist, he showed a deep interest in collecting and studying archaeological artefacts. While his main area of study was jade objects, he also published works on pre-Columbian goldsmithing technology in Costa Rica (Stone, 1961; Stone & Balser, 1958). However, these works do not mention the discovery of a crucible that could contextualise the MNCR 25648-2 artefact.

Reports from Costa Rica include finds of ceramic fragments with possible crucible characteristics, e.g. a whitish layer (Molina Muñoz, 2020). Potential use of ceramics for metal production was proposed by Ménager et al. (2025). They analysed fired bone (hydroxyapatite) coatings of sherds from two Costa Rican sites and found comparable evidence only in South America. As for neighbouring regions of Costa Rica, metallurgical crucibles were suggested for Colombia. From the Cauca valley, two containers are reported to be exceptionally large and thick-walled. They were interpreted as part of a portable melting furnace or melting pan. A written source from 1555 describes the practice of gold melting at Tamalameque, mentioning a crucible for melting “caricoli” (*guanín*) with gold (Bray, 1979). “Dirty sandstone” ceramic fragments from Rio Media Cauca in Colombia were investigated by Brooks et al. (2016). No visible gold was found by inspecting the sherds and under the microscope. However, elevated gold concentration was detected by ICP bulk analysis (367 ppm/122 ppm/91 ppm Au). The authors concluded that the micro-sized gold is, rather than being an indication of gold melting in a crucible, likely disseminated in the dark matrix of the ceramic or in the volcanic lithic fragments of the temper. Obviously, gold-bearing alluvial material was used to produce this ceramic. Analytical results from the study of colonial-period crucibles from northern Colombia characterised the local refractory fabrics as kaolinite-rich matrices with angular, porous quartz inclusions. Furthermore, the analysis of metallic microdroplets (*prills*) trapped within the vitrified walls revealed evidence of alluvial gold smelting, the processing of tumbaga alloys (gold, copper, and silver), and the early incorporation of silver into Colonial metallurgical practices (Martín-Torres et al., 2018).

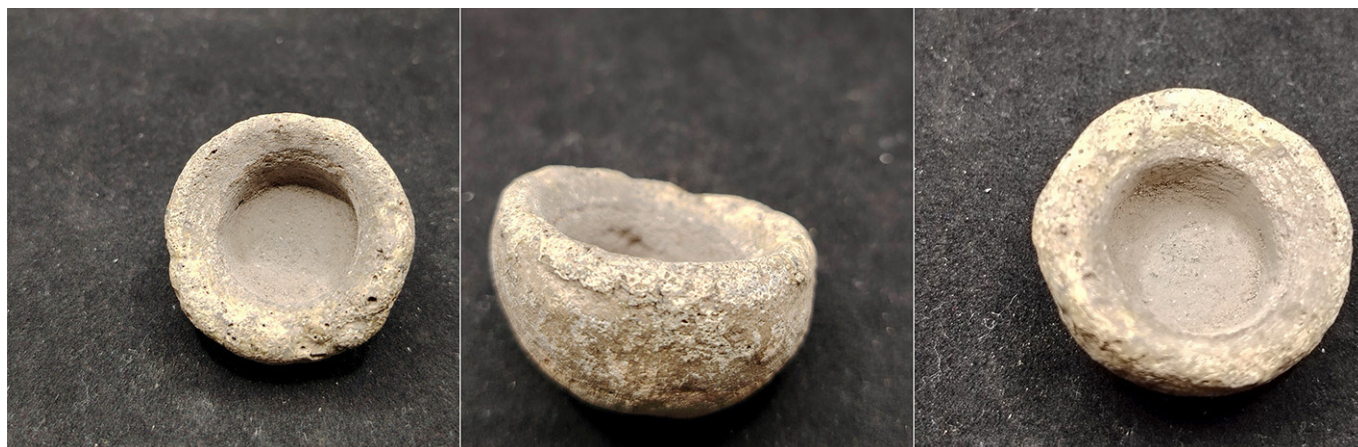


Figure 2: Views of the MNCR 25648-2 Crucible. Juan Carlos Calleja. Costa Rican National Museum Collection.

Analytical Approach

Digital microscopy

In the premises of MNCR at Pavas/San José (Sede José Fabio Góngora), the two objects were examined by digital microscopy using a handheld Proscope HR.

Scanning electron microscopy

The scanning electron microscope (SEM) enables the determination of the (main element) composition of the metal using an energy-dispersive X-ray spectroscopy system attached to the instrument, but also allows taking images at high magnification, which can provide a more specific perspective of the function and use of both objects. SEM is a non-destructive technique, does not necessarily require any preparation prior to the investigation and, therefore, does not affect the objects in any way.

The specimens were mounted on the SEM x/y/z/tilt/rotation sample holder and secured with modelling clay, which ensured stability during image acquisition without exerting pressure or damaging the surface (Figure 3). Since the investigated objects were considered as (potential) archaeological finds and the analyses had to be carried out non-destructively, no coating was used. The analyses were performed directly on the original surfaces. However, a conductive path had to be provided for the electrons in order to avoid charging artefacts. For this purpose, small strips of self-adhesive conductive tape were applied by touching one end to the region of interest, with the other end extending across the object's surface. Both the modelling clay and the conductive tape were removed after the procedure, leaving no visible residues.

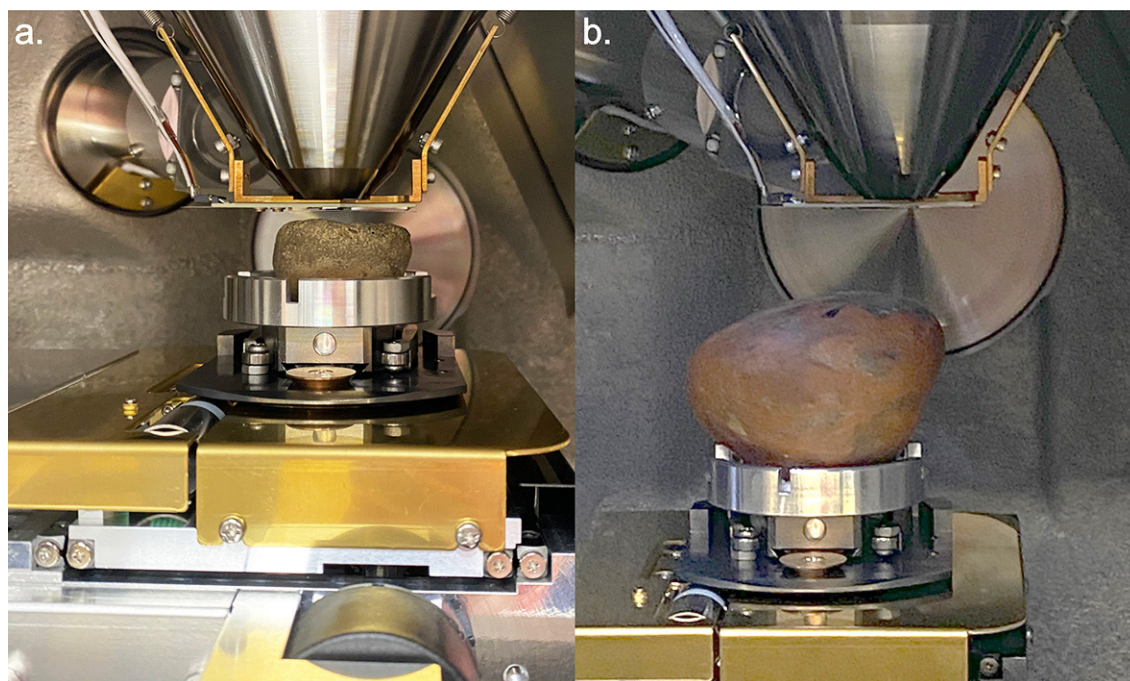


Figure 3: a. Crucible (left) and b. pebble (right) as positioned in the sample chamber of the SEM instrument.

The study was conducted using a JEOL IT-500 (JEOL, Japan) SEM instrument, located at the Department of Physics, National University of Costa Rica. The measurements were performed under low vacuum ($\sim 100\text{Pa}$) and 15 kV conditions with a backscatter electron (BED-S) detector. Energy-dispersive X-ray spectroscopy (EDX) was performed using a XFlash® Bruker system attached to the SEM. This procedure allowed for elemental mapping and the acquisition of point spectra from selected areas, enabling the qualitative identification of elements present in metallic droplets and in specific regions of the matrix. The areas analysed were chosen based on preliminary information obtained with the BED-S detectors, ensuring a correlation between morphology and composition. The quantification was carried out standardless. Therefore, a slight deviation of the analytical results from the true values cannot be completely ruled out.

Results and discussion

The “monochrome pot” – a metallurgical crucible

The crucible is made of tempered clay. Its rim is mostly covered by a vitrified, porous-to-bloated coating, identified by eye as scorified clay. The presence of scorified clay indicates the impact of high temperatures and suggests the crucible was used for metallurgical purposes. Not without some effort, a pair of

yellow, shiny, metallic *prills*, 200 μm in diameter, was found using the digital microscope, protruding from the surface and trapped in a vitreous area of the crucible. From the research context, the yellow colour of the *prills* suggested a gold-rich metal, but this needed to be confirmed by analysis.

First, the pair of droplets needed to be located in the SEM video image. While searching the rim for the droplet pair, it became evident that there were more yellow *prills* around the rim, albeit significantly smaller than those previously identified. They had globular shapes, indicating a previously fully liquid state. The *prills* were surrounded by a vitreous matrix, confirming the digital microscopy observation that the ceramic crucible was exposed to high temperatures. Their position at a slightly lower section of the crucible rim suggests they may have originated from pouring molten metal from the crucible, for example, to fill a casting mould. Contact between the hot molten metal and the ceramic crucible would then have caused partial liquefaction and local vitrification of the clay.

The two largest droplets, i.e. the pair identified by digital microscopy, were analysed for their elemental composition (Figure 4). The elemental mapping clearly distinguishes the gold-rich metal droplets from the surrounding siliceous crucible material, which also contains sodium, magnesium, calcium, iron and aluminium (Figure 5). In non-standardised point analyses of the droplets, copper was not detected, and silver contents were comparatively low with $\text{Ag}/(\text{Ag}+\text{Au}) \times 100$ ratios of up to 3.9 (Figure 5.c.). The metal droplets, therefore, result from the melting of unalloyed gold rather than gold-copper alloy (*guanín*), which was commonly used in pre-Columbian Costa Rica for casting (semi)plastic objects with the lost-wax technique (Fernández Esquivel, 2021).

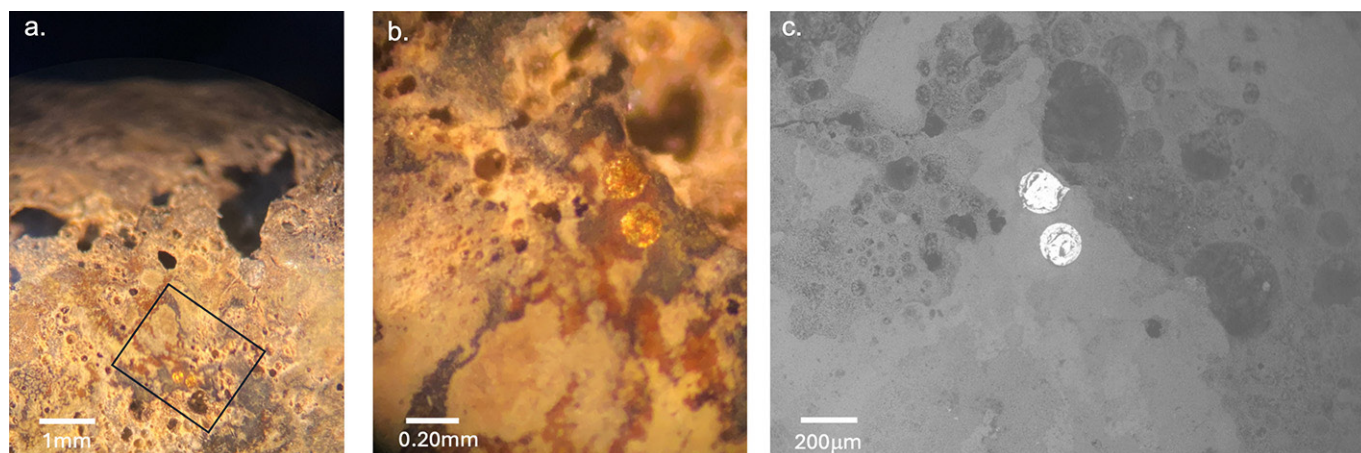


Figure 4: a. Photograph of the crucible rim with the investigated gold *prills*. b. 4x zoom of the two yellow *prills* c. Backscattered electron imaging of the prills. The two *prills* (white) are embedded in the ceramic crucible material (variable grey tones) and are directly surrounded by vitreous component.

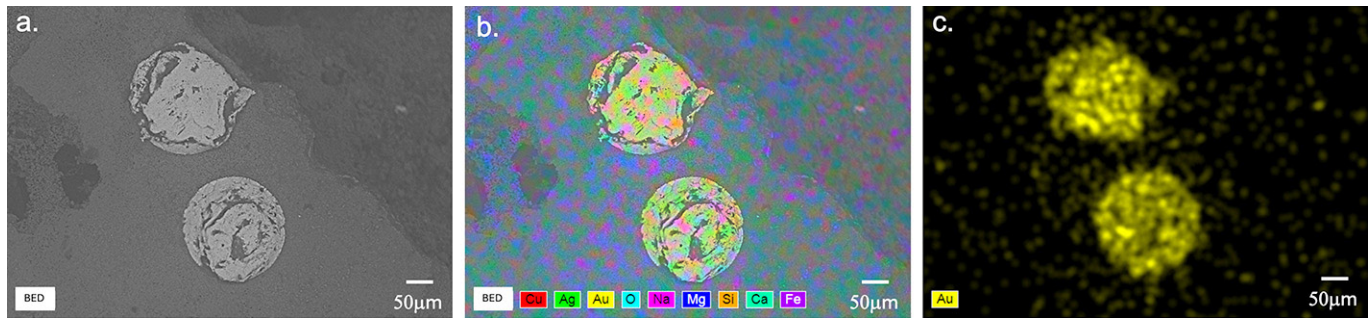


Figure 5: a. The mapped area in secondary electron imaging mode. b. Results of the elemental mapping visualising count rates of copper (Cu), silver (Ag), gold (Au), oxygen (O), sodium (Na), magnesium (Mg), silicon (Si), calcium (Ca), iron (Fe) and aluminium (Al) as a combined wrong-colour image. c. Isolated view of the gold count rates, clearly distinguishing the two metal *prills* from the surrounding matrix.

The peperite pebble – a burnishing tool?

Macroscopically, the peperite pebble consists of an intergrowth of red chert and black basalt components, resulting in irregular red and black areas. Yellow metallic (golden) areas visible on the surface appear to adhere to the basalt component and, when viewed under a microscope, appear patchy. Apart from the fact that the pebble is already the perfect size and shape for a hand stone by nature, no traces have been found to suggest that the stone was deliberately worked to make it more suitable for use as a tool.

Larger golden patches on the surface of the pebble were chosen for elemental analysis (Figure 6.a.). Height differences in the movement dimensions of the SEM stage between the stone's surface and the golden areas evidenced that they adhere to the smooth surface of the pebble as individual flakes. They have an anhedral, irregular shape, are frequently porous, and occur mainly as frayed patches (cf. Figure 6.b.). Scratches in the flakes are randomly oriented.

Non-standardised spot analyses in the core area of the adhering gold flakes determined $\text{Ag}/(\text{Ag}+\text{Au}) \times 100$ ratios between 10 and 13. Copper could not be detected. This is in agreement with the results of previous analyses of placer gold from the Osa peninsula (Abagna, 2025; Abagna et al., in preparation; Berrangé, 2011; this project). Furthermore, peperites with a similar composition as the investigated pebble, i.e. consisting of red chert and basalt, were observed at the bank of the Tigre River, a few kilometres upstream of the Cantarero site.

Peperites form due to interaction of magma and wet sediment (Skilling et al., 2002), in this case basaltic magma and chert. Chert was described to occur between lava flows of the Osa Igneous Complex, which constitutes the basaltic basement of the Osa Peninsula (Buchs et al., 2009) and represents the geological environment in which the peperite originally formed. Peperites of this composition and geographical origin have not been described for Costa Rica yet (Soto & Alvarado, 2012). The anhedral morphology of the gold adhering to the pebble is comparable to that of placer gold grains extracted from outcrops of auriferous sedimentary units at the Osa peninsula (Figure 7).

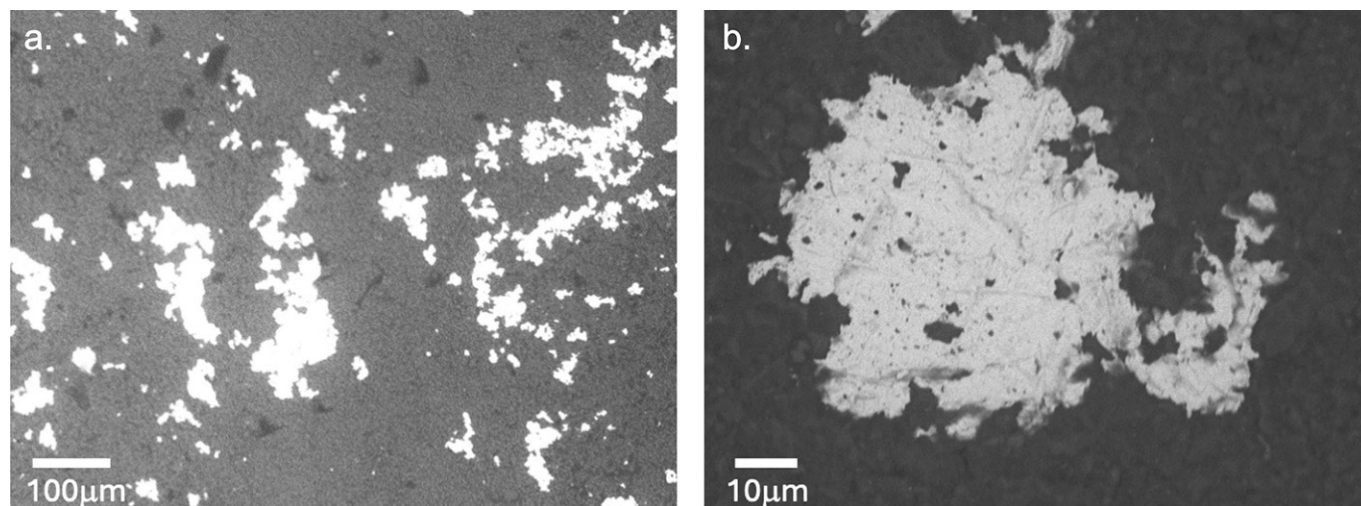


Figure 6: a. Overview of the investigated area of the pebble. Back-scatter electron image, 150-fold magnification. b. Detail view of an individual gold flake. Back-scatter electron image, 1200-fold magnification.

Based on the hypothesis that the pebble was used as a tool for goldworking or finishing of metal objects, polishing would likely have left parallel directional scratches on the gold flakes, while using the pebble as a hammering tool for joining individual gold flakes would have produced notable indentations on the surface. These activities would have flattened the flakes and closed their pores. Furthermore, pressure applied during tool use would be expected to cause grain elongation and boundary smoothing. However, no such working traces could be identified on the gold flakes adhering to the pebble.

The occurrence of placer gold on the Osa Peninsula further supports a non-anthropogenic origin of the gold observed on the pebble. Placer gold is widespread in the sedimentary unit unconformably overlying the Osa Igneous Complex (Berrangé, 1992). The sedimentary unit was generated by uplift and erosion of the Osa Igneous Complex (Berrangé, 1989) and thus can also contain clasts of peperites derived therefrom. The local association of peperite clasts with placer gold and the similarity in shape and composition of the gold on the pebble to those of placer gold grains found at the Osa peninsula are therefore fully consistent with a geological formation in the sedimentary unit overlying the Osa Igneous Complex or biogenic precipitation of the gold on the pebble surface during fluvial transport.

Conclusions

The crucible was part of the archaeological exhibition at the MNCR in the so-called Torre de Oro (Golden Tower) between the 1990s and 2010s, as an example of a tool used in gold smelting. However, it was not until this study that its specific use in the metallurgical chain was confirmed, revealing that it was

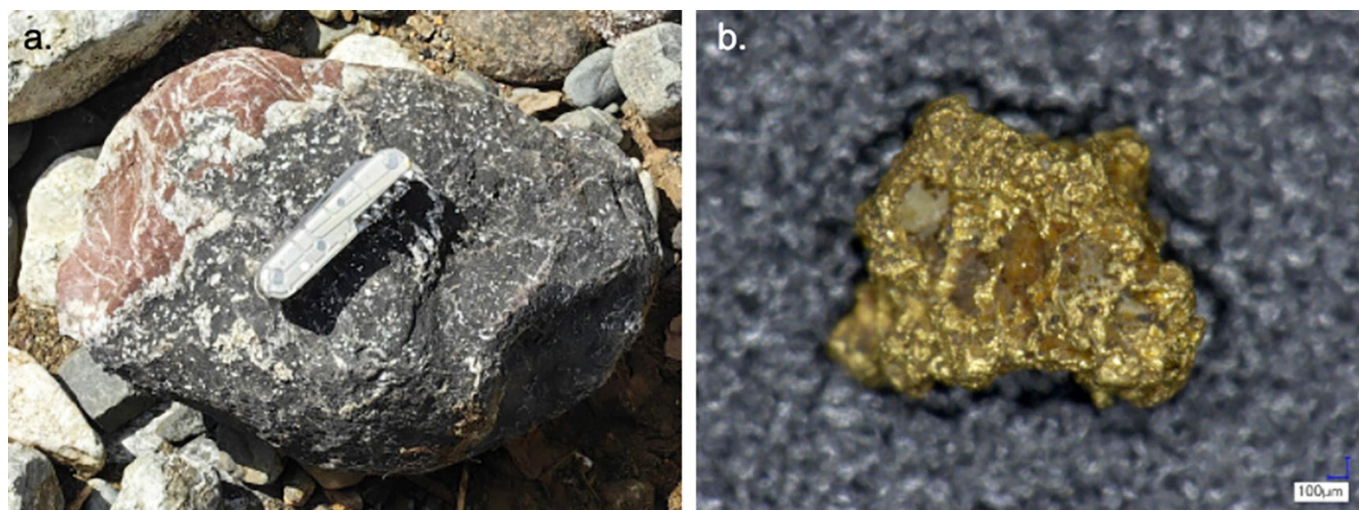


Figure 7: a. Peperite cobble stone, analogous to the investigated pebble consisting of chert (red) and basalt (dark), observed at the bank of the Tigre River during fieldwork. b. Anhedral and barely rounded grain of placer gold from the Rancho Quemado mining site at the Osa peninsula. Photography taken with a Keyence VHX-2000D digital microscope housed at the Deutsches Bergbau-Museum Bochum, research department of archaeometallurgy.

used to melt gold in a casting process. The results of the crucible analysis, especially the identification of its vitrified rim and yellow metallic droplets, provide evidence of local metal production and metallurgical expertise in pre-Columbian Costa Rica.

The peperite pebble was previously hypothesised to be a burnishing tool due to its yellow-metal coating. While the presence of gold on the surface was confirmed, no analytical evidence was found to suggest that the stone was used as a tool. All supporting arguments for this purpose were found to be negative. The gold on the surface of the peperite, a rock type associated with placer gold occurrences at the Osa peninsula, clearly was deposited in a natural process. For the Aguas Buenas period, there is still a lack of evidence of metal use, despite sites being located next to or even atop gold deposits and the regional use of metallurgical technology and objects. The reasons behind this situation remain a research challenge.

The examination of the two artefacts has provided significant insight into their nature and function. Only elemental analysis confirmed that the yellow metallic material in both objects was gold, enabling detailed compositional characterisation. In one case, the analysis demonstrated a metallurgical function for the artefact; in the other, it showed that the find was a natural occurrence rather than a metalworking implement. These examples underscore that an interdisciplinary approach to archaeological material is essential in order to achieve conclusive results and clarify ambiguous phenomena.

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