

Secondary Publication



Gassmann, Guntram; Vollstädt-Klein, Sabine; Schäfer, Andreas; u. a.

Investigating Pre-Columbian Gold and Copper in Costa Rica : Ores, Mines and Artefact Production

Date of secondary publication: 06.03.2026

Version of Record (Published Version), Article

Persistent identifier: urn:nbn:de:bvb:473-irb-114173x

Primary publication

Gassmann, Guntram; Vollstädt-Klein, Sabine; Schäfer, Andreas; u. a. (2023): Investigating Pre-Columbian Gold and Copper in Costa Rica : Ores, Mines and Artefact Production, in: Metalla : Forschungsberichte des Deutschen Bergbau-Museums, Bochum: Universitätsbibliothek der Ruhr-Universität Bochum, Vol. 27, No. 2, pp. 149–166, doi: 10.46586/metalla.v27.2023.i2.149-166.

Legal Notice

This work is protected by copyright and/or the indication of a licence. You are free to use this work in any way permitted by the copyright and/or the licence that applies to your usage. For other uses, you must obtain permission from the rights-holders.

This document is made available under a Creative Commons license.



The license information is available online:

<https://creativecommons.org/licenses/by/4.0/legalcode>

Investigating Pre-Columbian Gold and Copper in Costa Rica – Ores, Mines and Artefact Production

Guntram Gassmann, Sabine Klein, Andreas Schäfer, Elias Welk and Katrin Westner

Keywords

Mining archaeological prospection, geochemical analysis, stylistic feature analysis, Isthmo-Colombian region

Abstract

The wealth of pre-Columbian gold, copper and *guanín* (an alloy consisting mainly of gold and copper; also tumbaga) artwork of Costa Rica suggests that exploitation of its abundant ore deposits goes back way before the Spanish conquest. The name of Costa Rica itself in fact alludes to the large numbers of golden metal objects worn by the indigenous peoples upon arrival of the conquistadors. Up to now, however, very little is known about pre-Columbian mining in the country or the raw material provenance of these artefacts.

In a transdisciplinary project, we aim to reconstruct the metallurgical process chain by combining (mining) archaeological research with geochemical analysis of local ores and metal artefacts using a combination of different techniques. We identified four major gold and copper districts with different mineralisation types, which are the focus of our fieldwork-based research. They are surveyed for potential signs of pre-Columbian metal production and sampled for ores and their processing remains. On the other side of the process chain, we focus on the metal artefacts in museum collections. They are systematically registered in a database, which serves as a basis to identify correlations with the geochemical signatures of the artefacts, and to retrace potential links to possible areas of origin or different workshops. Once the necessary basic data have been collected, we will focus on economic and socio-cultural aspects of metal production and circulation. The results from Costa Rica will be put into perspective of New World early metallurgy and can provide a starting point for future research between Mesoamerica and the Isthmo-Colombian region.

Introduction

Pre-Columbian metal artwork of Costa Rica

The cultural and archaeological context

With its prominent location in Central America, Costa Rica was exposed to influences from both Mesoamerica in the north and the Isthmo-Colombian area in the south. Finds of locally worked jadeite and greenstone (so-called social jade; Alvarado and García-Casco, 2019) at burial sites mostly along the Línea Vieja of the Caribbean and the Pacific side of the Nicoya Peninsula (Figures 1 and 2) mirror their appreciation as prestige goods by Mesoamerican peoples (Balsler, 1961; Garber, et al., 1993; Doyle, Hoopes and Mora-Marín, 2021). Stylistic traits of lithic art similarly link northern Costa Rica with Mesoamerica while in the Diquís archaeological region in the southern part of the country (Figure 1), influences from Andean South America are predominant (Stone, 1961). Gold (-copper) artefacts seem to have slowly replaced jade objects as prestigious items in local society between AD 500-700 (Snarskis, 2003). Metal objects clearly played an important role in the ritual life of pre-Columbian societies. This socio-cultural perspective is essential for an understanding of ancient metal use.

Metallurgical knowledge is generally accepted to have advanced into Costa Rica from the south via Panama or the sea routes since metal work in Costa Rica, Panama and northern Colombia is characterised by commonly shared traits: the manufacture of artefacts by lost-wax casting, and the widespread utilisation of *guanín*, a copper-rich gold alloy, whose surface was artificially enriched by depletion gilding (e.g. Root, 1961; Bray, 1984). However, as most of the known artefacts from



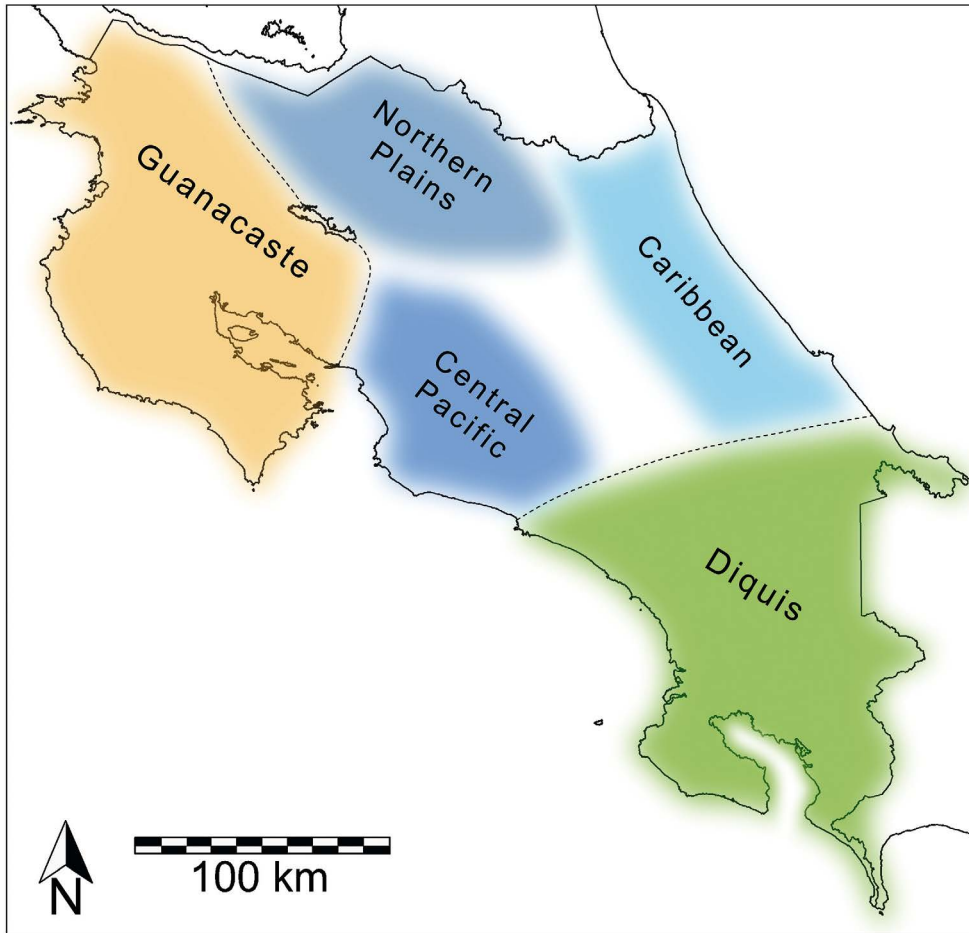


Figure 1. Archaeological complexes in Costa Rica adapted from Corrales Ulloa (2011). Graphic: E. Welk.

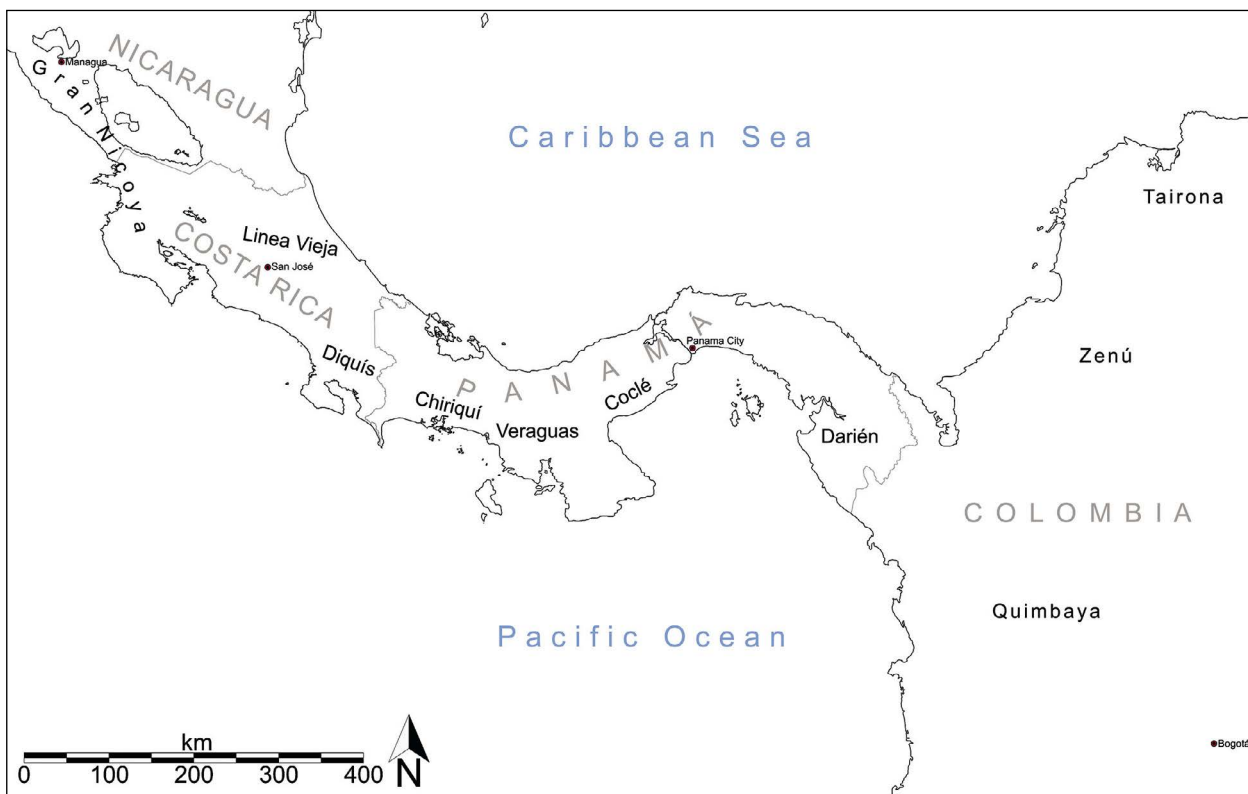


Figure 2. Pre-Columbian metal art styles in the Isthmo-Colombian area mentioned in the text. Graphic: E. Welk.

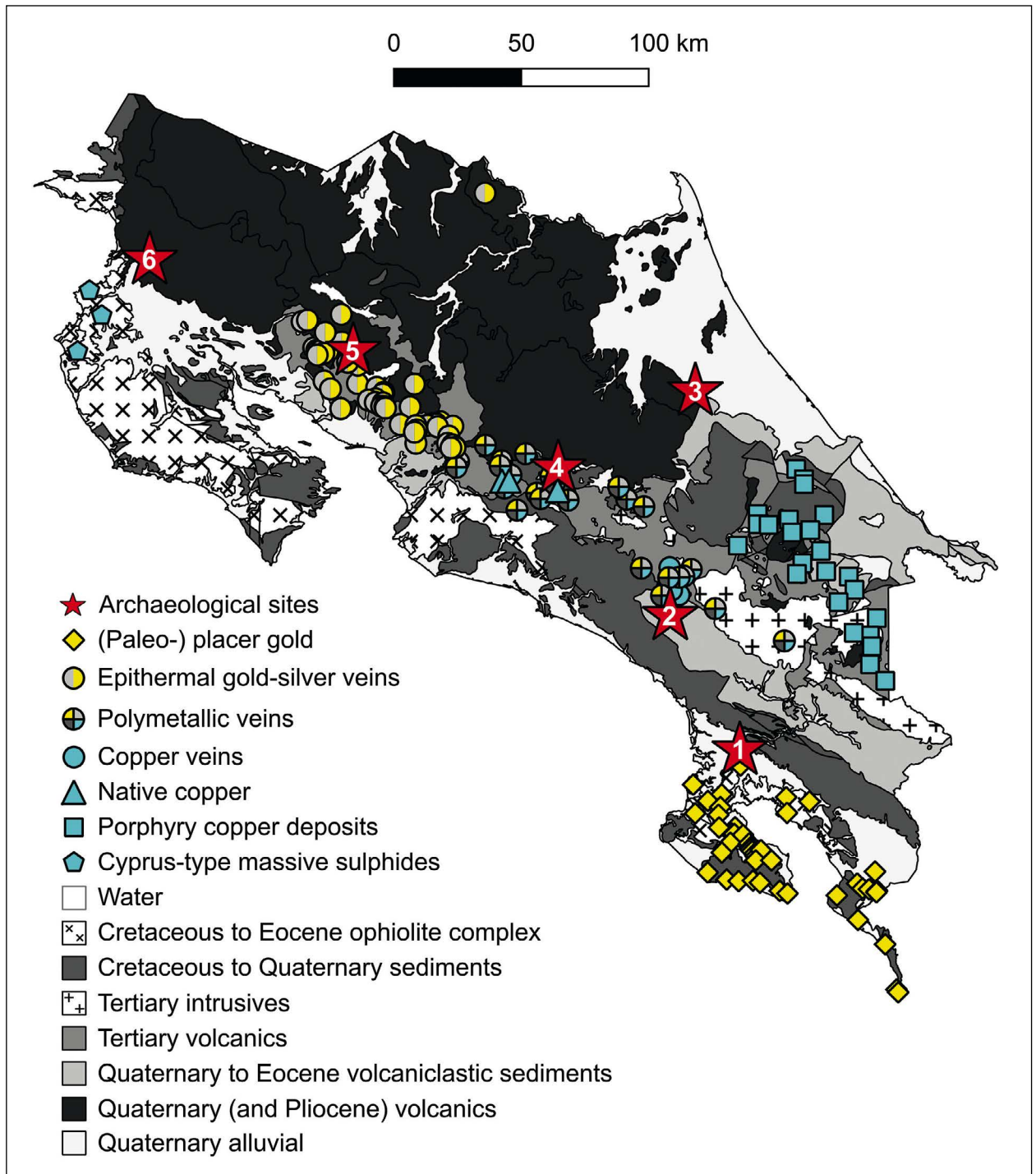


Figure 3. Simplified geological map of Costa Rica showing different types of gold- and copper-bearing mineralisation (United States Geological Survey, 1987; Nelson, 2007) and archaeological sites mentioned in the text: 1 - Finca 4; 2 - Rivas/Panteon de la Reina; 3 - Las Mercedes and Guacimo; 4 - Palo Campano; 5 - St. Elena; 6 - Ruiz. Graphic: K. Westner.

Costa Rica are not derived from archaeological contexts but from early pillaging (for example the famous site of Rivas/Panteón de la Reina near San Isidro de El General (Figure 3, number 2); Quilter, 2004 and references therein; Schlosser, 2004), the true origin and date, and in some instances also the authenticity of individual objects from museum collections remain to be discussed. The most widely used chronological framework derives from

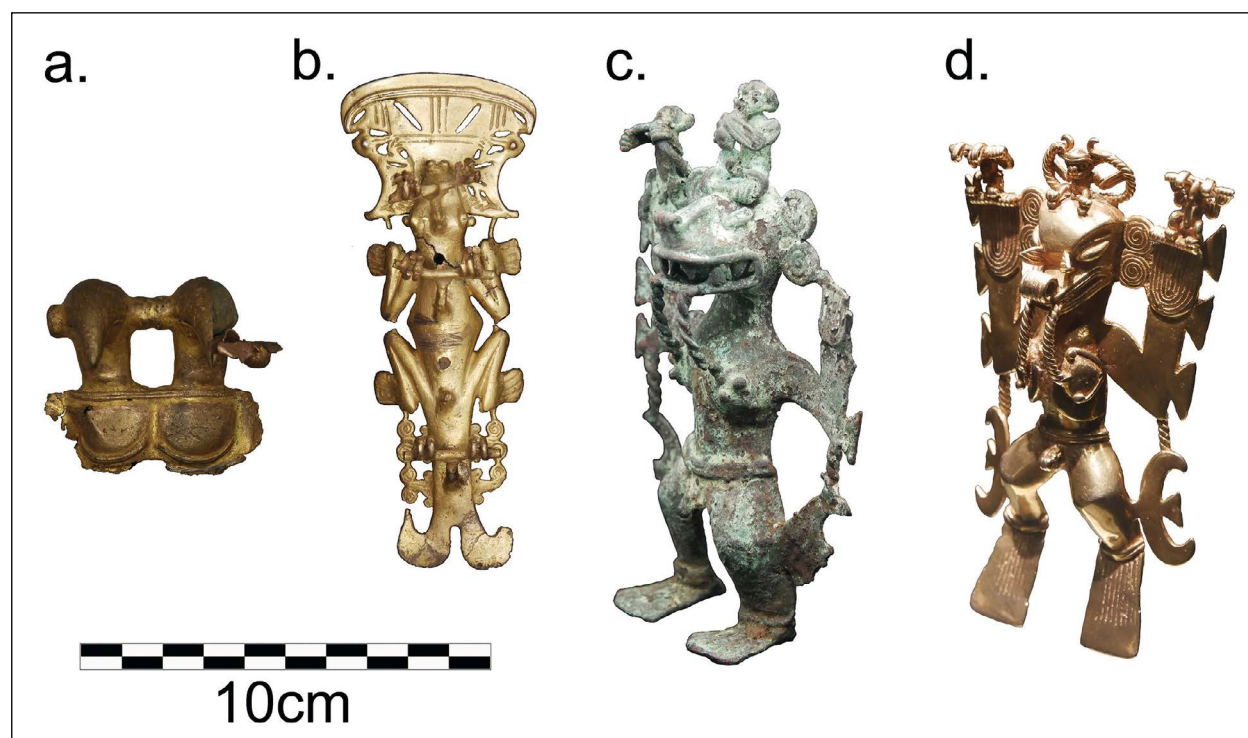
Cooke and Bray (1985) and is based on contextualized metal finds from Panamanian sites. It has been revised and refined repeatedly (see below) and has been applied to parts of Costa Rica as well.

One of the earliest assemblages with gold objects in Costa Rica, also containing jade objects and incised slate disks, is dated to around AD 400-600 (Snarskis, 1985) and has been discovered at a cemetery at Guáci-

mo (Figure 3, number 3) in the Línea Vieja region of the Caribbean (Stone and Balsler, 1965). The gold finds include a double-spiral pendant, human-figure pendant and a curly-tailed animal in the “Initial Group” postulated by Cooke and Bray (1985) and Bray (1992), which is dated AD 1-500 and stylistically similar to artefacts from northern Colombia (Tairona, Zenú, Quimbaya; e.g. Fischer, 1994; Jones and King, 2002). Several jade objects from Guácimo also represent curly-tailed animals, exemplifying the jade-gold transition. Further characteristic objects of the Initial Group include double-headed birds and pendants with two or more conjoined animals (Figure 4a). Las Mercedes (Figure 3, number 3), also in the Línea Vieja region, is considered as an important pre-Columbian centre based on its monumental architecture (causeways, platforms; Hartman, 1902), and plethora of metal artefacts of the Initial Group as well as of later date (e.g. the so-called jaguar god; MacCurdy, 1911), which unfortunately were unearthed in unscientific excavations. The subsequent “International Group”, dated between AD 500 and 900 (Figure 4b), occurs in a wide geographical region from northern Colombia up to the Yucatán Peninsula in eastern Mexico. It includes birds with outstretched wings, elongated crocodile-shaped ornaments, simple human figures and others with recurved headdresses, and so-called “Darien” pendants (Falchetti de Sáenz, 1979; Bray,

1992; Falchetti, 2008). The Veraguas-Gran Chiriquí metal tradition (dated AD 900-1520) brings together similar artwork from western Panama and the southern Caribbean to the wider Diquís region in southwestern Costa Rica (Figures 4c and d) and existed until the contact period (Cooke and Bray, 1985; Bray, 1992). It is characterised by birds with outstretched wings, frogs, jaguars, crocodiles and animal-headed anthropomorphic figures often with flattened feet or extremities, and comprises both cast and sheet metal objects (Fernández and Quintanilla, 2003). The Diquís region yielded some of the richest pre-Columbian gold finds in Costa Rica (Lothrop, 1963), including the objects brought to light in Palmar Sur at Finca 4 (Figure 3, number 1; Badilla, Quintanilla and Fernández, 1997). Metallurgy appears to have started later in southwestern Costa Rica than in the rest of the country as no metal objects have been found at any of the sites of the Aguas Buenas period (300 BC-AD 800) in the Diquís subregion (Figure 5). However, some human stone sculptures attributed to this period apparently depict metal pendants (Hoopes, 2017), which makes it plausible to infer a certain level of knowledge regarding the use of metal objects. At present, the chronological framework is not detailed enough to provide a clear picture of the introduction of the use of metals in the Diquís region. Furthermore, it is unclear whether metallurgical knowledge was intro-

Figure 4. Selected gold, guanín and copper artefacts from the National Museum of Costa Rica (MNCR) and the Museo del Oro Precolombino of the Central Bank of Costa Rica (BCCR) in San José. a) Initial Group (MNCR 25506); b) International Group (MNCR 25560); c) Diquís Style (MNCR 27747); d) Diquís Style (BCCR-O-1250). Photos: A. Schäfer, graphic: E. Welk.



		Greater Nicoya		Central Region			Greater Chiriquí			
AD		Guanacaste Subregion		Caribbean	Central Pacific	Northern Plains	Diquís Subregion		AD	
1500		Ometepe		La Cabaña	Cartago	Venecia	Chiriquí		1500	
		Sapoá								
800		Bagaces		La Selva	Curridabat	Platanar	Aguas Buenas		800	
		Tempisque								
±1		El Bosque		Pavas	Ron Ron				±1	
300									300	
	BC									BC

Figure 5. Archaeological phases in Costa Rica in the regions outlined in Figure 1 from the 3rd century BC up to the contact period (adapted from Corrales Ulloa, 2011). Graphic: A. Schäfer.

duced from the neighbouring Chiriquí and Veraguas regions in Panama or was derived from the central and northern parts of Costa Rica, where metal artefacts had already been used before.

Since more than 90 % of the known pre-Columbian metal artefacts from Costa Rica and Panama are decontextualised (see above), aspects of chronology, development of metal production and regional assignments are under constant discussion and revision (Cooke and Bray, 1985; Bray, 1992; Cooke, Sánchez and Udagawa, 2000; Cooke, 2011; Bray, Cooke and Redwood, 2021; Fernández Esquivel, 2021). What is true for Panama (Cooke, 2011) applies to Costa Rica as well. It is as yet not really possible to reconstruct the development of metal use - let alone metal production- in the main cultural areas of Costa Rica (i.e. Greater Nicoya, Central Region, Greater Chiriquí and their subregions; Figures 1 and 5). Nevertheless, despite the lack of context, stylistic subgroups have been defined, based on typological characteristics especially of figurative art in order to draw conclusions about their possible chronology and provenance (Aguilar Piedra, 1972; Fernández and Quintanilla, 2003; Fernández Esquivel, 2011). A major conundrum still surrounds the earliest known metal artefacts from Costa Rica, and thus the beginning of metalworking and use of metallurgical technology throughout the country. It is still unclear whether or how many of the earliest objects were imported from

the Isthmo-Colombian region, or from elsewhere, and to what extent and when (or if at all) production in local workshops began.

A final remark needs to be made regarding the importance and value of the various metals, both in pre-Columbian times and in contemporary research. To date, the focus of archaeological research has been almost exclusively on gold and *guanín* objects, with copper objects often being mentioned only in passing. Due to their corroded appearance and often precarious state of preservation they are also rarely exhibited and certainly severely underrepresented in most collections. If, 45 years ago, Lange and Accola (1979) concluded that most of the (altogether few) pre-Columbian copper objects from (northern) Costa Rica should be regarded as imports from Mesoamerica, the time is certainly right for a reconsideration based on today's much broader material record. With intriguing ideas about the social significance of gold or copper objects for pre-Columbian societies in the Isthmo-Colombian area (e.g. Falchetti, 2003), and the observation that there are distinct artefact categories such as bells or specific types of figurative art made in almost identical form from both metals (cf. Figure 4c, d), there can be no doubt about the importance of copper for the study of metal artefacts. And finally, *guanín*, which is the metal alloy for the whole of the Isthmo-Colombian region, has a copper content of between 40 and 80 per cent (see below).

Metal artefact analyses: the state of the art

The Museo Nacional de Costa Rica (MNCR) and the Museo del Oro Precolombino, as well as museums in the United States and Europe, host a wealth of pre-Columbian objects made of gold and *guanín*, and more rarely, of gold-poor or unalloyed copper. Analytical studies (Rovira, 1994; Scott, 1995; Fernández and Quintanilla, 2003; Schlosser, 2004; Fernández Esquivel, 2011) almost exclusively focused on objects that were either derived from southern Costa Rica or interpreted as having been made in the unified style of Veraguas-Gran Chiriquí from the Chiriquí Period, the last period of the pre-Columbian chronological sequence. They showed that the majority of cast artefacts (whose proportion in collections clearly outweighs that of sheet metal) consists of a gold-copper alloy with small amounts of silver (mostly < 5 wt.%). No overall correlations between their shape, and their stylistic group and thus relative chronology were found so far (e.g. Scott, 1995). Among other potential reasons such as availability of raw materials, colour, hardness and odour of the alloys, the preference for copper-rich gold alloys might have been linked to the lowering of the melting point by the addition of copper (up to c. 150 °C; Okamoto, et al., 1987) and a hence simplified casting process. Despite their composition, most of these objects have a gold surface colour. A commonly used technique to generate this effect is depletion gilding, which is based on the higher resistance of gold to oxidation. The gold alloy objects are treated with natural etching agents to superficially remove copper (and silver) and are subsequently polished (Lechtman, 1984; Bray, 1993; also see Sáenz-Samper and Martín-Torres, 2017). Cast copper objects with low or undetected gold and silver contents (Fernández Esquivel, 2011) in the form of bells and anthropomorphic and avimorphous figures are particularly known from sites in central and northern Costa Rica. Lange and Accola (1979) describe the find of a copper bell from a burial site in north-western Costa Rica and interpret it as an import from either Honduras or Mexico, where major production sites for these artefacts have been identified (see above). Sheet metal objects in contrast generally have a lower copper content and often seem to have been made of unalloyed gold. This choice of material might have been due to the lower hardness and thus easier workability of (relatively) pure gold, which can be laminated into thin foils; another reason might be the generally smaller amount of metal needed.

So far, in general only non-destructive analyses of pre-Columbian metal objects have been carried out. Obtaining reliable bulk chemical information is impeded when using such analytical techniques due to commonly

applied surface treatments such as depletion gilding, as well as the widespread usage of *guanín* which easily corrodes after its deposition due to the climatic conditions of the country. These processes lead to an enrichment of gold in the uppermost zone of the artefacts which renders surficial analyses misrepresentative of the bulk composition. The existing data exclusively have been obtained by surface analysis; only partially the analyses could be performed at abraded locations of the artefacts where the core metal is exposed. With few exceptions (some analyses presented in Schlosser, 2004) measurements were limited to major and minor elemental composition. No trace element data could be determined and no isotope analyses had been carried out so far. The available results thus largely exclude a data-driven discussion of fundamental aspects such as the possible provenance of raw materials, including the amount of imported versus locally produced objects, the ore types used, and the technological know-how. A further critical aspect of the existing literature data is the focus on metal objects which are tentatively assigned to the late Veraguas-Gran Chiriquí style and/or originated from find sites in the south of Costa Rica, therefore underrepresenting earlier phases of metal objects and other archaeological complexes in the country.

Ore resources and pre-Columbian metal production

Different types of gold and copper deposits are distributed throughout Costa Rica (Figure 3). Primary gold deposits occur as silver-rich epithermal gold-quartz veins (low sulphidation type) in a c. 80 km long, NW-SE trending belt within the Cordillera de Tilarán and are associated with basalts, andesites and andesitic breccia of the Aguacate Group. The mineralisation is assumed to have been generated in the late Pliocene to early Pleistocene by hydrothermal circulation of meteoric water, which was presumably triggered by the emplacement of the granitic Guacimal intrusion (Mixa, et al., 2011). The epithermal gold-silver vein deposit of Crucitas is located close to the border with Nicaragua within the Miocene Sarapiquí volcanic belt (Gazel, et al., 2006). The mineralisation is hosted by trachyandesitic-dacitic to rhyolitic dome complexes and pyroclastic rocks, which are strongly oxidised to a precious metal-bearing saprolite down to an average depth of 40 m (Lafleur, 2006). Auriferous (paleo-) placers at the Península de Osa (Figure 6) are present within residual latosols of the ophiolitic Upper Cretaceous to Lower Tertiary Nicoya Complex and the overlying sediments of the Osa and Puerto Jiménez Groups. Gold is mainly abundant in the lower units of the Osa Group, where the highest concentrations are as-

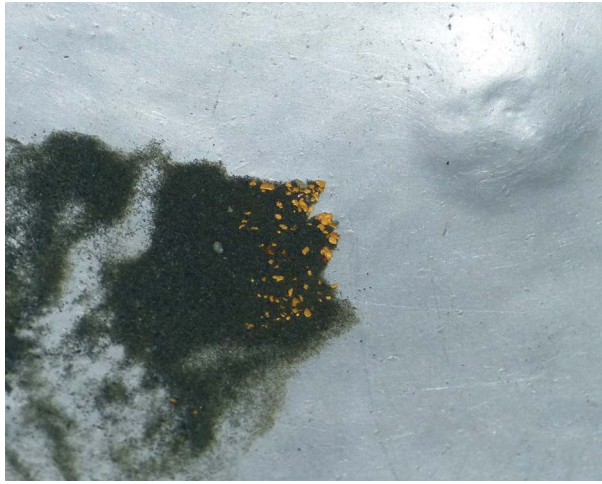


Figure 6. Washing pan with gold flakes and heavy mineral sand from a paleo-placer occurrence at the Osa Península in the south of Costa Rica (image width c. 5 cm). Photo: A. Schäfer.

sociated with basal breccia conglomerates. Exceptional nuggets reportedly had the size of an orange and weights of up to 7.7 kg (Berrangé, 1992). Copper mineralisation occurs as (polymetallic) base metal veins in a zone directly adjoining the epithermal gold deposits of the Cordillera de Tilarán to the southeast, as Cyprus-type volcanic-hosted massive sulphides (VMS) at the Peninsula de

Nicoya (in the west of the country) and porphyry copper deposits in the Cordillera Talamanca (e.g. United States Geological Survey, 1987). Native copper occurs as thin sheets (up to c. 3 mm thick) in fractures in andesite at e.g. Guayabo de Mora (Figure 7).

A contemporary report of indigenous gold extraction after the Spanish conquest solely describes panning of placers (Fernández de Oviedo, 1851; book VI, chapter VIII). The historic evidence, the abundance of rich (paleo-) placer gold deposits of the Península de Osa and the wealth of artefact finds in the Diquís region (e.g. at Finca 4), gave rise to the generally accepted notion that only the secondary gold mineralisation was exploited in pre-Columbian time (e.g. Molina Muñoz, 2017). Some years ago, however, evidence for pre-Columbian hard-rock extraction (stone tools, i.e. hammer stones and mortars, curved rock shapes characteristic of fire setting) was discovered at the Río Grande and Río Coclé del Sur Basins, Panama, in an area with attested primary and secondary gold mineralisation (Mayo, et al., 2007). Based on a geological examination, it is hypothesised that gold, jarosite for use as a pigment, or agate were possibly won there (Redwood, 2020). The close connection between Panama and (southern) Costa Rica, evidenced for example by the shared stylistic traits of metal artefacts, renders it highly plausible that the knowledge of

Figure 7. Sheets of native copper (arrows) at the Guayabo de Mora outcrop in the Central Region. Photo: A. Schäfer.





Figure 8. Half of a ceramic casting mould for a frog pendant from Ruiz, Guanacaste. Height 6.8 cm. Photo: A. Schäfer.

such exploitation techniques was common throughout the region. Pre-Columbian gold production in Costa Rica thus might not only have been restricted to riverine deposits. It certainly is likely that consolidated auriferous paleo-placers in the Diquís region, if traced back from their alluvial occurrences, were exploited in shallow diggings before the arrival of the Spaniards. In a wider and more general perspective, hard-rock mining was practised in the central Andean region since the Formative Period (e.g. Tripcevich and Vaughn, 2013).

The primary gold ores of the Cordillera de Tilarán are assumed to only have been discovered in the 19th century (Soto, 2011). However, as outlined above, the appearance of gold artefacts is an earlier feature in the archaeological record of the central and northern regions of Costa Rica than in the south. Clear evidence of local gold working, i.e. fragments of ceramic casting moulds for frog pendants and other ornaments are also known from the north (Figure 8; Fernández Esquivel and Faith Jiménez, 1991). The presence of pre-Columbian settlement sites and cemeteries with gold objects near the mining districts of the Cordillera de Tilarán (e.g. Santa Elena, Tibás, Palo Campano; V. Guerrero, pers. comm.) and the large amount of (copper-debased) gold sourced

by the Spaniards during an expedition in Greater Nicoya in the first half of the 16th century (García Regueiro, 1985) further emphasize that there is a potential for gold production in central and northern Costa Rica. This should be investigated.

Copper is commonly assumed to have been mostly produced from native occurrences in pre-Columbian Costa Rica (e.g. Molina Muñoz, 2017). Due to the comparatively small volume of this mineralisation, it is however questionable whether they could have supplied the amount of metal required for the production of *guanín* and copper artefacts known today from Costa Rica, as well as the mass of objects already melted down by the conquistadors (Fisher, 1976). This far, no secure evidence for copper production is known from the Costa Rican (and associated Panamanian) archaeological complexes. An object made of unalloyed copper discovered at Sitio Conté/Panama shows that its inhabitants had access to highly pure copper metal. The find of a copper ingot (91.9 wt.% Cu) and partially worked ore (94.1 wt.% Cu) at the site however might not have been of local origin but obtained by trade (Lothrop, 1937).

As a first-order conclusion, the overall abundance of ore deposits in Costa Rica seems to make it very plausible that most of the known objects were made from raw material(s) of local origin, thus increasing the potential for successful provenance studies of metal artefacts. However, no mining archaeological and archaeometallurgical studies have yet been carried out in the country that could provide factual evidence for this hypothesis by identifying production sites and elucidating the types of ore used and the processes employed to extract metals.

Goals and perspectives of the investigations

Several research questions and desiderata have been already outlined in different paragraphs of the introduction. They can be summarised as follows: 1) identifying and localising potential remains of metal mining and production from ore extraction to the finished object, 2) characterising different types of gold and copper ores accessible to pre-Columbian people, 3) reconstructing potential raw material sources of metal objects and pyrometallurgical technological choices, 4) identifying practices and techniques of metal craftsmanship, and 5) establishing a classification of stylistic features of metal objects, identifying possible groups and testing correlations with e.g. spatial distribution, chronology, and metal composition. Combining archaeological and analytical research methods, we aim to tackle these questions in cooperation with local colleagues.

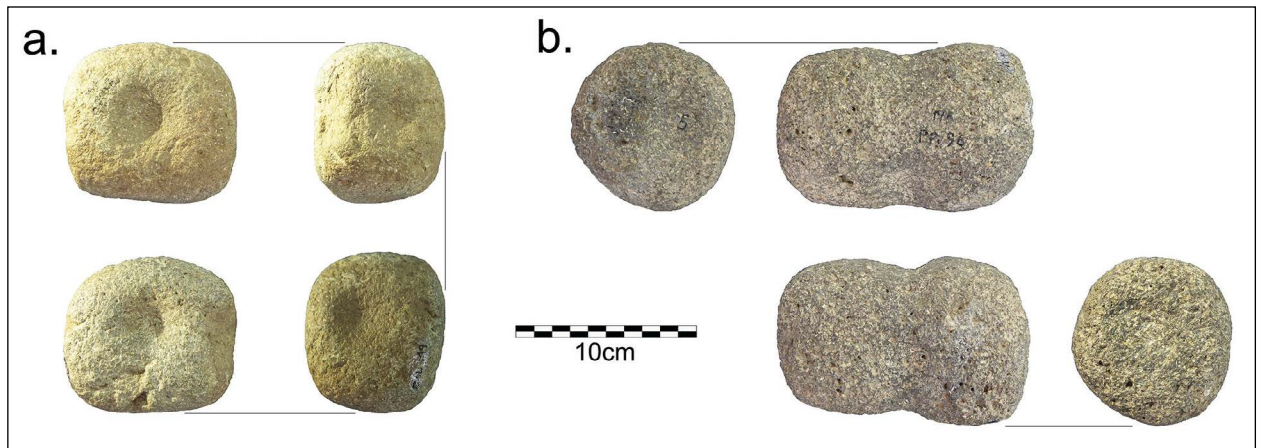


Figure 9. Two crushing stones (front, back and side views) from the collection of the Anthropological Institute of the Universidad de Costa Rica. Photos: E. Welk.

Research methods

Archaeological investigations

Mining-archaeological studies

Mining-archaeological studies within the project focus on fieldwork. They aim to identify and localise potential working sites and associated material evidence for the process chain from ore to finished metal object (e.g. Stöllner, 2003; Hauptmann, 2020). A number of key aspects have been defined:

- a) **Evidence for mining of primary and secondary gold and copper deposits:** Possible indications include shafts, galleries, and opencast pits (specifically for hard-rock mining and extraction of paleo-placer gold), evidence of water management, i.e. artificial channels and dams, and signs of digging (for exploitation of placer gold), and in general debris heaps, as well as finds of e.g. mining hammers, transport containers for ores, washing pans, and sluice boxes. In general, the exploitation of placer gold deposits leaves little tangible evidence on-site. Picking-up of nuggets from riverbeds in dry periods is invisible in the archaeological record. Ancient panning of fluvial placer gold would also be difficult to detect in the field, if not combined with indirect evidence as described above.
- b) **Signs for ore beneficiation:** These include stone tools for crushing and grinding the ore, anvil stones, mortars, and heaps of fine-grained debris. A first glance at some collections of pre-Columbian stone tools in Costa Rica already revealed evidence of crushing stones (Figure 9) typical for ancient ore beneficiation, well known from a variety of archaeological mining contexts as in Peru (Gräfinholt, 2022).

- c) **Traces of pyrometallurgical processes for primary ore (s)melting and subsequent artefact production in workshops:** Potential evidence comprises furnaces or fire pits, tuyéres, slags and other metallurgical (by-) products such as ingots, and crucibles, moulds, and tools associated with such processes. Native copper occurring in the form of sheets at some deposits in contrast could be directly melted together with gold in crucibles for the production of *guanín* artefacts or could be cold-worked, with potential evidence for its use thus being limited.
- d) The existence of chronological phases and/or spatial differences for production and refinement processes.

The focus of the mining-archaeological studies are surveys within the different gold and copper ore districts of Costa Rica. By taking into account major archaeological sites with pre-Columbian metal objects, four main target regions for field work, which comprise types of ore deposits presumed to have been most likely accessed by pre-Columbian societies, have been identified. Namely these are the copper mineralisation in the Central Valley, including occurrences of native copper (around archaeological site number 4 in Figure 3), the (polymetallic) copper deposits in the hinterland of San Isidro de El General (number 2), the primary gold deposits in the Cordillera de Tilarán (number 5), and the (paleo-) placer gold of the Península de Osa (number 1). The shallow oxidised gold mineralisation of Crucitas constitutes a further potential target area for fieldwork. The porphyry copper and VMS deposits have been excluded for now due to (1) the largely disseminated nature of the ore which renders it less likely to have been mined in pre-modern time and (2) the absence of visible outcrops of ore bodies, respectively (cf. United States Geological Survey, 1987).

Together with colleagues from the National Museum of Costa Rica, we will furthermore assess material from earlier fieldwork, including archaeological excavations of pre-Columbian settlements and cemeteries with associated metal finds. The material evidence will be checked for the presence of tools for mining and beneficiation, and metallurgical materials (such as crucibles, moulds and equipment used for metal working) which can be easily misinterpreted or left unidentified. Archaeological excavations at sites related to pre-Columbian metal mining and production are envisaged for the future, if possible.

Typological analysis and object database

To date, the classification of metal artefacts has been based on the first overall presentation of Costa Rican metal artwork in the large collection of the Banco Central (now Museo del Oro Precolombino) by Carlos Aguilar Piedra (1972) and, in particular, on the studies of Richard Cooke and Warwick Bray (Cooke and Bray, 1985; Bray, 1992; Cooke, Sánchez and Udagawa, 2000; Cooke, 2011; Bray, Cooke and Redwood, 2021), who have defined different chronological and stylistic groups (see above).

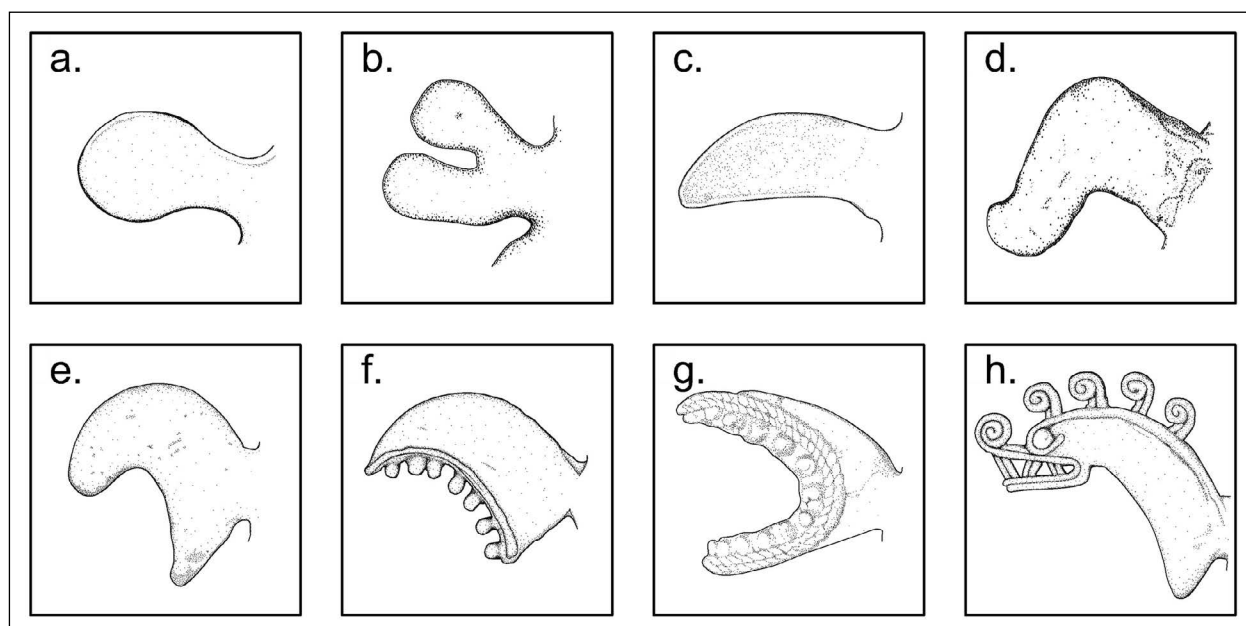
In order to facilitate comparisons between object style and metal composition, it may be feasible to place more emphasis on typological detail and to arrive at a classification based on feature analysis.¹ Typology, in this case, should not be confined to a detailed stylistic classification but should include technological parameters,

i.e. details on production and ornamentation techniques and surface finish as well. Together with the material analyses (see below) this methodological approach could help to differentiate, in the future, true imports from local imitations, as is under constant discussion, especially for the Initial Group as defined by Cooke and Bray (1985). A feature analysis breaking down the material into individual features and attributes could help to arrive at a conclusive and comprehensive classification for all of the metal artefacts.

We have begun to build a database of Costa Rican metal artefacts, starting with the more than 2000 artefacts from the Museo del Oro Precolombino, which became available online in 2021.² This was followed in spring and summer 2023 by the autopsy of the 782 metal artefacts from the National Museum, including the important but, still a rather limited group of metal objects with a clear archaeological context, and artefacts from some European museum collections, which are available online. Objects held in other museum collections and described in publications will gradually be included. The metal objects from the collection of the Ethnological Museum in Berlin, Germany (see Schlosser, 2004) have already been included.

In practice, our data structure consists of a hierarchical and flexible system of categories with underlying common attributes (e.g. in the case of figurines: heads, feet, hands, wings, etc.) and special attributes (instruments, tools, additional heads, animals, etc.). The differentiation extends to the diversity of stylistic detail

Figure 10. Compilation of differently shaped wings of Costa Rican figurative metalwork (different scales). Drawings: E. Welk, based on the objects BCCR-O-1384 (a), -0816 (b), -0822 (c), 0154 (d), -0795 (e), -1274 (f), -0452 (g), -1247 (h) from the collection of Museo del Oro Precolombino in San José.



of individual attributes (Figure 10). This approach will make it possible to recognise and quantify recurring combinations of individual elements and subsequently to define distinct groups on the basis of their similarities. The analytical data collected in the project (see below) will then be linked to the individual objects. By comparing the stylistic groups, potential links to possible areas of origin or different workshops could be identified. For a chronological and/or regional evaluation of the identified stylistic groups, the (few) contextualized artefacts in particular from the MNCR, will be of paramount importance. Production debris such as fragments of casting moulds (Figure 8) are also of great importance and will be included in the database. Combined with a systematic evaluation of metal artefacts from recent excavations, there is great potential for a more detailed chronological and regional assessment of the development of metal production and craftsmanship in Costa Rica.

Material analyses

Ores

Understanding mineralisation within its regional geology (e.g. Ferenčić, 1971; Alvarado and Cárdenes, 2015) is essential for retracing possible raw material sources of metal objects. The analysis of different types of gold and copper ores potentially used for pre-Columbian artefact production therefore forms the basis of our study.

Samples of primary and (paleo-) placer gold ores, and of native copper, and of secondary and sulphide copper minerals will be collected during mining-archaeological surveys in the target areas (see above). Samples will be taken from geological outcrops and as heavy mineral concentrates in the case of placer gold, or if available, from potential archaeological contexts. Heavy mineral concentrates will be collected in regular distances from each other to assess chemical differences caused by transportation distance (also see section below). Creeks cutting auriferous mineralisation in the Cordillera de Tiláran will be also sampled for heavy mineral concentrates to further assess whether they would also constitute a potential source used in pre-Columbian metal production.

A bundle of state-of-the-art analytical methods is available at the research laboratory of the Deutsches Bergbau-Museum Bochum and the Frankfurt Isotope and Element Research Centre (FIERCE) for a thorough mineralogical and geochemical characterisation: Optical microscopy, scanning electron microscopy (SEM-EDX), electron microprobe analysis (EMP), X-ray powder diffraction (XRD), (laser ablation) single-collector inductively coupled plasma mass spectrometry (SC-ICP-MS)

for compositional analysis down to the trace element level, and multi-collector (MC) ICP-MS for determination of Pb and Cu isotope ratios. Gold grains from heavy mineral concentrates of alluvial placers will be additionally studied for their morphological characteristics, e.g. degree of roundness, flatness, rim thickness and proportion, and associated minerals (Knight, Morison and Mortensen, 1999; Townley, et al., 2003) and chemical depletion during transportation. Possibly present osmium-iridium-ruthenium alloys which might have been derived from ophiolitic rock sequences of the Nicoya complex associated with the auriferous (consolidated) sediments (Berrangé, 1992) will be particularly sought for due to their high significance for gold artefact studies (see below).

At the time this text was written, a first field work campaign (apart from a previous pilot study) has already been carried out and some preliminary analytical data already are available. A general first-order observation was that, due to Costa Rica's tropical climate, ores from outcropping copper mineralisation usually are strongly weathered and (largely) transformed to oxidised (e.g. malachite, brochantite) minerals or iron-poor to iron-free copper sulphides (e.g. covellite, chalcocite, bornite). The apparent mineralogy of hand samples thus indicates a rather "pure" bulk composition without elevated quantities of e.g. iron, zinc, arsenic and lead to be expected. Therefore, these ores could be smelted for their copper content for example in a pit or fired clay crucible with only minor slagging, constituting a comparatively easily accessible source for copper.

Preliminary results from semi-quantitative SEM-EDX analyses (SUPRA 40 VP, Zeiss) of gold grains and available literature data (Berrangé, 1992; Scott, 1995; Fernández and Quintanilla, 2003; Mixa, et al., 2011) suggest that gold grains from the Cordillera de Tilarán (Au/Ag ratios from 1.4 to 1.9) can be distinguished from (paleo-) placer gold of the Península de Osa by their significantly higher silver content (Au/Ag ratios between 33.5 and 181.2). Copper is below 1 wt.% in both ore types, and thus would result in comparatively pure gold compositions, if used directly. Analyses of sheets of native copper by ICP-MS (Element XR, Thermo Fisher Scientific) showed that elements other than copper are in sum below 1 wt.%.

The Pb isotope composition of ores reveals information on the U-Th-Pb ratios of their metal source(s) depending on geological events and reservoirs, and the age of separation of U and Th from Pb during precipitation of lead-containing minerals, which discontinued further enrichment of ^{206}Pb , ^{207}Pb and ^{208}Pb by radiogenic decay of parental ^{238}U , ^{235}U and ^{232}Th (e.g.

Tosdal, Wooden and Bouse, 1999; Huston and Champion, 2023). This coupling of information is a powerful tool to reconstruct metal sources and metallogenetic processes in ore deposit formation, and by comparison with artefact data, to identify their possible raw material origin (see below). However, the application of Pb isotopes might be limited in the present project since the lead contents might be too low or possibly unrelated to ore formation in some samples, for example lead in placer gold ores might not be of primary origin but rather have been derived from e.g. associated sedimentary rocks (Kamenov, et al., 2013). Contrary to Pb isotopes, varying proportions of ⁶⁵Cu and ⁶³Cu mostly are related to low-temperature redox processes and therefore depend on the formation history of the ores (e.g. Asael, et al., 2012; Mathur and Zhao, 2023). Apart from data collection for comparison with metal artefact data, the Cu isotope ratios of native copper are particularly interesting from a geological perspective to elucidate on its formation conditions and processes.

Metal artefacts

Investigation of metal artefacts from museum collections will be closely coordinated with the responsible curators and adjusted to the specific prerequisites. Due to unique character of the objects and their exceptional archaeological value, non-destructive studies naturally are of high importance and priority.

Aspects of pre-Columbian metal craftsmanship are planned to be studied of selected objects from museum collections with a high-resolution digital microscope. These comprise production techniques (casting, hammering, laminating, cutting etc.), surface treatments (depletion gilding, leaf gilding, polishing), joining techniques (sintering, soldering, granulating), traces of working processes and tools used, including secondary and modern traces (e.g. polishing, chipped off metal), shapes, forms and dimensions of objects (potential standardisation and variation in archaeological complexes or stylistic groups), production units (craftsmen, workshops, socio-economic groups, regional differences) and metallurgical aspects (alloy variation versus pure metals – different colours and thus conclusions on the composition possible). Possible inclusions of the platinum group elements (PGE), specifically osmium-iridium-ruthenium alloys in the gold artefacts visible by naked eye or by digital microscopy can indirectly testify to the utilisation of placer gold (e.g. Ogden, 1977; Meeks and Tite, 1980), provided that primary PGE-bearing rocks were in close vicinity so that the PGEs were found associated with gold in the placer. Osmium-iridium-ruthenium alloy inclusions can be expected in gold derived from

the Península de Osa (as outlined above) while their potential source rocks are absent from the geological record of the Cordillera de Tiláran. They thus can allow (further) discrimination between primary and secondary gold of Costa Rican occurrences. Additionally, artefacts from Mesoamerica (Nicaragua, Honduras) and the Isthmo-Colombian zone (Panama, Colombia) are planned to be studied with digital microscopy to retrace (reciprocal) influences on metal craftsmanship from the neighbouring regions, but also to investigate the possible transfer of metallurgical technology in the broader region, including the origin of the earliest known metal objects from Costa Rica.

For a first-order non-destructive characterisation of the alloy composition and identification of depletion gilding layers on-site, objects from museum collections will be analysed using portable X-ray fluorescence (pXRF) and their specific density will be determined. Since pXRF measurements are carried out directly at the surface, they will deliver representative main element compositional data for objects which were not treated by depletion gilding or whose core metal is exposed due to for example previous testing, and which are not or only slightly corroded. While measurement of gilded *guanín* objects will result in a mixed analysis of surface and core metal, it will at least enable us to clearly distinguish them from artefacts made of untreated gold (alloy). In contrast to pXRF, which only allows determining the near-surface composition, the specific density method represents the composition of the entire object. While internal cavities (German: *Lunker*) may somewhat distort the measurement, the results will nonetheless provide a meaningful first impression of the composition.

For detailed analyses, necessary to address complex questions of raw material provenance of artefacts (lead isotope analyses etc.) it will be *sine qua non* to be able to take metal samples of museum objects for laboratory analyses. Objects well suited for such minimally invasive analysis (e.g. by micro-drilling) will be broken off parts of (stylistically identifiable) artefacts, or artefacts with visible traces of earlier sampling or testing. Such metal specimens will be analysed for their chemical composition down to the trace element level by solution-based ICP-MS. Elemental signatures depend on the type of ores used, and subsequent metallurgical processing and metal working (cf. Hauptmann, Rehren and Pernicka, 1995; Guerra and Calligaro, 2004; Bendall, et al., 2009; Ehser, Borg and Pernicka, 2011; Numrich, et al., 2023). Since the vast majority of at least cast metal objects are deliberately alloyed with copper, their elemental pattern will represent a mixture of different raw material types. A database of potential ores therefore is a prerequisite of

any discussion of likely gold and copper sources utilised, and to evaluate their respective contribution to the objects' geochemical patterns. Such a database will be established for Costa Rica in this project, while reference data from neighbouring regions are available elsewhere (e.g. Macfarlane and Lechtman, 2016, for South America; Klein, et al., 2022, for aspired global coverage).

Some elements are characteristic for ore types. For example, trace amounts of PGEs detected in analyses of placer gold from the Península de Osa (Berrangé, 1992) have the potential to distinguish it from primary gold of the Cordillera de Tilarán due to the different geological style of mineralisation. The low proportion of “impurities” detected in preliminary analyses of native copper and gold grains from the Península de Osa indicates that, if elevated amounts of, e.g. sulphur, tellurium, nickel, and antimony are detected in the metal artefacts, they would be introduced by the utilisation of more complex raw materials such as copper ores with (restitic) sulphide minerals. While inclusions of osmium-iridium-ruthenium compounds will be left unchanged by metallurgical processing, platinum and palladium will enter the liquid together with gold (Barnes, Naldrett and Gorton, 1985; Bockrath, Ballhaus and Holzheid, 2004). The contents of other elements might be affected by volatilisation (e.g. sulphur, zinc) due to oxidising conditions that can prevail in simple metallurgical installations where air flow cannot be thoroughly controlled. Elemental patterns of ores and artefacts therefore mostly cannot be compared directly. Since isotopic fractionation decreases proportionally with temperature, the influence of metallurgical processes on isotope signatures commonly is negligible. They thus can be used to link raw material sources and artefacts, rendering Pb isotopes the arguably most important tool for data-driven provenance analysis of archaeological metal objects (Killick, Stephens and Fenn, 2020; Klein, et al., 2022). However, as already pointed out in the previous section, application of Pb isotopes might be limited due to the possibly low lead contents of some potential ores. Furthermore, the lead abundances in gold artefacts often are very low and hence would necessitate rather large sample sizes that usually are not available. Copper isotope patterns can yield important insight into the ore types used (Klein, et al., 2004) and can potentially be used to identify mixing in related artefacts. Coupling compositional and isotopic data, we would aim to narrow down or exclude mining districts from which metals were or were not sourced. Subsequently generalised geological (and geographical) correlations between ores and objects as well as production debris, if available, will be established. The hypotheses on the raw material supply established by these data will be collected in a GIS data-

base comprising results from the field surveys to identify potential connections with other archaeologically relevant findings.

The silver contents of pre-Columbian metal objects from Costa Rica analysed so far (Rovira, 1994; Scott, 1995; Fernández and Quintanilla, 2003; Schlosser, 2004; Fernández Esquivel, 2011) generally fit well to available data of (paleo-) placer ores from the Península de Osa but do not match the comparatively silver-rich composition of primary gold from the Cordillera de Tilarán (Berrangé, 1992; Fernández and Quintanilla, 2003; Mixa, et al., 2011; preliminary data from this project). Since most artefacts investigated so far either originate from the broader Diquís area in the south of Costa Rica and/or have been tentatively assigned to the style of this region, this observation indicates the importance of local (gold) resources for artefact production. However, as mentioned above, it also reflects an artefact bias that leads to an underrepresentation of objects from central and northern Costa Rica, including the earliest archaeological contexts with metal finds. A systematic investigation of their (main element) composition has yet to be performed, to which we aim to contribute with our study. Another aspect to consider is the extent of compositional variation of primary gold ores from the Cordillera de Tilarán, and specifically the impact of fluvial transport which increases the Au/Ag ratios of gold grains by preferential leaching of the less noble silver. However, the electrum-like composition of epithermal gold investigated so far in any case contradict the long-held assumption that pre-Columbian metal artefacts with an elevated silver content are imports from the south (where highly argentiferous gold deposits are known) and were not produced from local resources (see for example Lothrop, 1937 for artefacts found in Sitio Conté, Panama).

Due to the widespread utilisation of copper-rich gold alloys, a central technological aspect is to reconstruct how the *guanín* was produced, i.e. if native or smelted copper was used. As described above, oxidised copper ores abundant in Costa Rica provide a comparatively easily accessible source of copper and thus offer a potential alternative supply of the metal. It also has to be assessed whether copper and gold were mixed in particular ratios to generate alloys with favourable characteristics, e.g. better casting properties, increased hardness and particular colour or odour. Furthermore, we will investigate whether the alloy composition is correlated with spatial, stylistic and chronological differences.

By all means, the importance of the resource copper in pre-Columbian Costa Rica should not be underestimated. During cataloguing objects for the database, it

became evident that gold rarely was used without added copper for the manufacture of cast artefacts, whose number is clearly larger than those of sheet metal objects. The inventory of the metal artefacts of the MNCR which arguably comprises the least biased object collection in terms of e.g. alloy composition and preservation and shape of the objects, hosts a number of objects made of seemingly gold-poor or even unalloyed copper. The potential local sources of copper (from native copper or other types of copper ores), the origin and development of possible metallurgical knowledge necessary to use these raw materials, or the trade contacts which served to either access copper metal for local workshop production or to import finished objects, are of principal importance of our understanding of pre-Columbian Costa Rican metalworking.

Outlook: a Socio-cultural perspective of metal production in Costa Rica

Stepping back from the material-based aspects, it is necessary to be aware of the far-reaching social implications of metal working (cf. Eliade, 1980; Falchetti, 2003; Shimada and Craig, 2013). What was its true role in indigenous societies? For which purposes were metals used and who handled them? Did metal objects serve as symbols of power or status and prestige, were they part of ritual practices or some other activities (Snarskis, 1985; Hosler, 1995; Fernández and Segura Garita, 2004)? Were there economic/cultural contacts with other cultural groups or elites that led to the exchange of prestige goods? Numerous theories and reflections on the role and importance of early metallurgy exist for Central America and mainly are based on iconographic and stylistic grounds and artefact distribution (aptly drawn together in Quilter and Hoopes, 2003).

Our systematic characterisation of ore deposits and metal artefacts will build a comprehensive data basis for early metallurgy of Central America, i.e. Costa Rica for a start, and will enable to evaluate existing socio-cultural interpretation models. Current hypotheses, e.g. for the south of Costa Rica, favour a setting in which inland chiefdoms controlled the gold-bearing rivers in the south from afar (Corrales Ulloa, 2021). The material basis is particularly crucial for the interpretation of raw material circulation, preferred trade routes and exchange networks and the socio-cultural implications derived from these aspects. Due to the high level of research input in the Diquís delta, including the Península de Osa, this important part of southwest Costa Rica may develop into a key case study for the role metal pro-

duction and use played in ancient societies of Central America.

In cooperation with Ancient American studies, drawing on methods from applied geochemistry, archaeometallurgy, experimental archaeology, ethnoarchaeology, ethnohistorical studies and comparative artefact studies, we aim to explore these aspects at a later stage of the project. As Costa Rica features both ties to cultures of the north (Mesoamerica) and the southeast (Panama and Colombia), it provides a perfect starting point for a re-appraisal of the cultural impact of early metallurgy and its development in (southern) Central America.

Acknowledgements

Several visits to the country (since 2016), including a German Research Foundation (DFG)-funded Initiation of International Collaboration (SCHA 1486/6-1), led to the establishment of a sound cooperation basis with the Museo Nacional de Costa Rica in San José, the capital of Costa Rica. Many thanks are due to our Costa Rican colleagues for all their support and patience during the long preparation stage, both in the field and in paving all the bureaucratic ways. We are especially grateful for our cooperation with Ifigenia Quintanilla, director of the MNCR as well as Myrna Rojas and Francisco Corrales from the Department of Anthropology of the MNCR, who generously provided full access to the objects from the museum collection. We also would like to thank the National Archaeological Commission (CAN) for creating the basic prerequisites for our engagement in Costa Rican archaeology. Finally, the DFG is given credit for providing the necessary funding (project number 470821474).

Notes

- 1 At this stage of the study, the authors' understanding of the style and typological grouping cannot yet be specified, but only after completion of the typological characterisation and feature analysis based on the object database.
- 2 The structure tree of the database created is a preliminary basic scheme that will be adapted in the course of the project. For the final evaluation, the central similarity criterion should be subdivided into qualitative and quantitative aspects. At this stage, however, it is too early to go into further detail on these aspects.

All authors contributed to and agreed upon the final version of the manuscript. The author names have been ordered alphabetically.

References

- Aguilar Piedra, C.H., 1972. *Colección de objetos indígenas de oro del Banco Central de Costa Rica [Collection of indigenous gold objects of the Central Bank of Costa Rica]*. Publicaciones de la Universidad de Costa Rica, Serie Historia y Geografía 13. San José: Universidad de Costa Rica.
- Alvarado, G.E. and Cárdenes, G., 2015. Geology, tectonics, and geomorphology of Costa Rica: A natural history approach. In: M. Kappelle, ed. 2015. *Costa Rican ecosystems*. Chicago: The University of Chicago Press. pp.30-63.
- Alvarado, G.E. and García-Casco, A., 2019. Jade social precolumbino en Costa Rica: una revisión de la diversidad petrográfica, fuentes de materia prima y posibles rutas comerciales [Cost Rican Precolumbian social jade: A review of petrographic diversity, raw material sources and potential exchange routes]. *Cuadernos de Antropología*, 29(1), pp.1-17. <https://doi.org/10.15517/cat.v1i1.35538>.
- Asael, D., Matthews, A., Bar-Matthews, M., Harlavan, Y. and Segal, I., 2012. Tracking redox controls and sources of sedimentary mineralization using copper and lead isotopes. *Chemical Geology*, 310-311, pp.23-35. <https://doi.org/10.1016/j.chemgeo.2012.03.021>.
- Badilla, A., Quintanilla, I. and Fernández, P., 1997. Hacia la contextualización de la metalurgia en la subregión arqueológica Diquís: El caso del sitio Finca 4 [Towards the contextualization of metallurgy in the Diquís archaeological subregion: The case of the Finca 4 site]. *Boletín Museo del Oro*, 42, pp.113-137.
- Balsler, C., 1961. 14: Some Costa Rican Jade Motifs. In: S.K. Lothrop, ed. 1961. *Essays in Pre-Columbian Art and Archaeology*. Harvard University Press. pp.210-217.
- Barnes, S.J., Naldrett, A.J. and Gorton, M.P., 1985. The origin of the fractionation of platinum-group elements in terrestrial magmas. *Chemical Geology*, 53(3-4), pp.303-323. [https://doi.org/10.1016/0009-2541\(85\)90076-2](https://doi.org/10.1016/0009-2541(85)90076-2).
- Bendall, C., Wigg-Wolf, D., Lahaye, Y., Von Kaenel, H.M. and Brey, G.P., 2009. Detecting Changes of Celtic Gold Sources Through the Application of Trace Element and Pb Isotope Laser Ablation Analysis of Celtic Gold Coins. *Archaeometry*, 51(4), pp.598-625. <https://doi.org/10.1111/j.1475-4754.2008.00423.x>.
- Berrangé, J.P., 1992. Gold from the Golfo Dulce placer province, southern Costa Rica. *Revista Geológica de América Central*, 14, pp.13-37. <https://doi.org/10.15517/rgac.v0i14.13172>.
- Bockrath, C., Ballhaus, C. and Holzheid, A., 2004. Fractionation of the Platinum-Group Elements During Mantle Melting. *Science*, 305(5692), pp.1951-1953. <https://doi.org/10.1126/science.1100160>.
- Bray, W., 1984. Across the Darien Gap: A Colombian View of Isthmian Archaeology. In: F.W. Lange and D. Stone, eds. 1984. *The Archaeology of Lower Central America*. Albuquerque: University of New Mexico Press. pp.305-338.
- Bray, W., 1992. Sitio Conte Metalwork in Its Pan-American Context. In: P. Hearne and R.J. Shearer, eds. 1992. *River of Gold: Precolumbian Treasures from the Sitio Conte*. Philadelphia: University Museum, University of Pennsylvania. pp.33-46.
- Bray, W., 1993. 16 - Techniques of gilding and surface-enrichment in pre-Hispanic American metallurgy. In: S.L. Niece and P. Craddock, eds. 1993. *Metal Plating and Patination*. Oxford: Butterworth-Heinemann. pp.182-192. <https://doi.org/10.1016/B978-0-7506-1611-9.50020-0>.
- Bray, W., Cooke, R.G. and Redwood, S.D., 2021. Early Metalwork in Caribbean Colombia and Southern Central America. In: C. McEwan and J.W. Hoopes, eds. 2021. *Pre-Columbian Art from Central America and Colombia at Dumbarton Oaks*. Harvard: Harvard University Press. pp.541-568.
- Cooke, R. and Bray, W., 1985. The Goldwork of Panama. An Iconographic and Chronological Perspective. In: J. Jones, ed. 1985. *The Art of Precolumbian Gold. The Jan Mitchell Collection*. New York: The Metropolitan Museum of Art. pp.34-45.
- Cooke, R.G., 2011. The Gilcrease Collection and Gran Cocle culture area of Panama: An assessment of provenience and chronology with comments of the iconography of pottery and metal-work. In: R.G. Cooke, N.J. Saunders, J.W. Hoopes and J. Quilter, eds. 2011. *To Capture the Sun: Gold of Ancient Panama*. Tulsa: Gilcrease Museum. pp.129-173.
- Cooke, R.G., Sánchez, L.A. and Udagawa, K., 2000. Contextualized goldwork from 'Gran Cocle', Panama: an update based on recent excavations and new radiocarbon dates for associated pottery styles. In: C. McEwan, ed. 2000. *Precolumbian Gold: Technology, Style and Iconography*. London: British Museum Press. pp.154-176.
- Corrales Ulloa, F., 2021. Monumentality and Portability. Stone Spheres and Gold Ornaments from the Diquís Delta. In: C. McEwan and J.W. Hoopes, eds. 2021. *Pre-Columbian Art from Central America and Colombia at Dumbarton Oaks, Pre-Columbian Art at Dumbarton Oaks*, 5. Washington D.C.: Dumbarton Oaks Research Library and Collection. pp.249-261.
- Doyle, J., Hoopes, J.W. and Mora-Marín, D., 2021. Shining Stones and Brilliant Regalia. Connections between Classic Mesoamerica and Central America and Colombia. In: C. McEwan and J.W. Hoopes, eds. 2021. *Pre-Columbian Central America, Colombia, and Ecuador: toward an integrated approach*. Washington D.C.: Dumbarton Oaks Research Library and Collection. pp.89-99.
- Ehser, A., Borg, G. and Pernicka, E., 2011. Provenance of the gold of the Early Bronze Age Nebra Sky Disk, central Germany: geochemical characterization of natural gold from Cornwall. *European Journal of Mineralogy*, 23(6), pp.895-910. <https://doi.org/10.1127/0935-1221/2011/0023-2140>.
- Eliade, M., 1980. *Schmiede und Alchemisten [Blacksmiths and alchemists]*. Stuttgart: Klett-Cotta.
- Falchetti, A.M., 2003. The Seed of Life: The Symbolic Power of Gold-Copper Alloys and Metallurgical Transformations. In: J. Quilter and J.W. Hoopes, eds. 2003. *Gold and Power in Ancient Costa Rica, Panama, and Colombia*. Washington D.C.: Dumbarton Oaks Research Library and Collection. pp.345-381.
- Falchetti, A.M., 2008. The Darién Gold Pendants of Ancient Colombia and the Isthmus. *Metropolitan Museum Journal*, 4, pp.39-73.

- Falchetti de Sáenz, A.M., 1979. Colgantes 'Darien'. Relaciones entre Areas Orfebres del Occidente Colombiano y Centroamerica ['Darien' pendants. Relations between Goldsmith Areas of Western Colombia and Central America]. *Boletín Museo del Oro*, 2, pp.1-55.
- Ferenčić, A., 1971. Metallogenic provinces and epochs in southern Central America. *Mineralium Deposita*, 6(1), pp.77-88. <https://doi.org/10.1007/BF00207119>.
- Fernández de Oviedo, G., 1851. *Historia general y natural de las Indias, islas y tierra firme del mar océano. Primera parte [General and natural history of the Indies, islands and mainland of the ocean sea. First part]*. Madrid: La Real Academia De La Historia.
- Fernández Esquivel, P., 2011. *Metalurgia y Relaciones Sociales en el Sur de América Central (300-1500 D.C.) [Metallurgy and Social Relations in the South of Central America (300-1500 AD)]*. Master thesis Universidad de Costa Rica.
- Fernández Esquivel, P., 2021. Metallurgy in Costa Rica. In: C. McEwan and J.W. Hoopes, eds. 2021. *Pre-Columbian Art from Central America and Colombia at Dumbarton Oaks, Pre-Columbian Art at Dumbarton Oaks*, 5. Washington D.C.: Dumbarton Oaks Research Library and Collection. pp.239-247.
- Fernández Esquivel, P. and Faith Jiménez, E., 1991. *Museo oro precolombino [Pre-Columbian gold museum]*. San José: Departamento de Museo, Banco Central de Costa Rica.
- Fernández, P. and Quintanilla, I., 2003. Metallurgy, balls, and stone statuary in the Diquís Delta, Costa Rica: Local production of power symbols. In: J. Quilter and J.W. Hoopes, eds. 2003. *Gold and power in ancient Costa Rica, Panama, and Colombia. A symposium at Dumbarton Oaks 9 and 10 October 1999*. Washington D.C.: Dumbarton Oaks Research Library and Collection. pp.205-244.
- Fernández, P. and Segura Garita, J., 2004. Costa Rica south-east metallurgy: Local productions identification based on technological and stylistic evidence. In: A. Perea, I. Montero and Ó. García-Vuelta, eds. 2004. *Ancient gold technology: America and Europe*. Madrid: Consejo Superior des Investigaciones Científicas. pp.49-61.
- Fischer, M. ed., 1994. *El Dorado - Das Gold der Fürstengräber [El Dorado - The Gold of the Princely Graves]*. Berlin: Dietrich Reimer.
- Fisher, J.R., 1976. Gold in the search for the Americas. *Gold Bulletin*, 9(2), pp.58-63. <https://doi.org/10.1007/BF03216611>.
- Garber, J.F., Grove, D.C., Hirth, K.G. and Hoopes, J.W., 1993. Jade Use in Portions of Mexico and Central America. Olmec, Maya, Costa Rica, and Honduras - A Summary. In: F.W. Lange, ed. 1993. *Precolumbian Jade: New Geological and Cultural Interpretations*. Salt Lake City: University of Utah Press. pp.211-231.
- García Regueiro, O., 1985. Oro y descubrimiento: la expedición de Gil González Dávila [Gold and discovery: the expedition of Gil González Dávila]. *Cuadernos Hispanoamericanos*, 418, pp.5-33.
- Gazel, E., Alvarado, G.E., Obando, J. and Alfaro, A., 2006. Geología y evolución magmática del Arco de Sarapiquí, Costa Rica [Geology and magmatic evolution of the Sarapiquí Arc, Costa Rica]. *Revista Geológica de América Central*, 32, pp.13-31. <https://doi.org/10.15517/rgac.v0i32.4242>.
- Gräffingholt, B., 2022. *Pre-Columbian Mining and Resource Production between Southern Peru and Northern Chile. An Analysis of the Exchange Processes Concerning Lithic and Metal Resources Used by the Pre-Columbian Cultures in the Andes*. Der Anschnitt, Beiheft, 48. Bochum: Deutsches Bergbau-Museum, Rahden/Westfalen: Verlag Marie Leidorf.
- Guerra, M.F. and Calligaro, T., 2004. Gold traces to trace gold. *Journal of Archaeological Science*, 31(9), pp.1199-1208. <https://doi.org/10.1016/j.jas.2002.05.001>.
- Hartman, C.V., 1902. Arkeologiska undersökningar på Costa Ricas ostkust [Archaeological investigations on the east coast of Costa Rica]. *Ymer*, 1, pp.19-55.
- Hauptmann, A., 2020. *Archaeometallurgy - Materials Science Aspects*. Natural Science in Archaeology. Cham: Springer International Publishing. <https://doi.org/10.1007/978-3-030-50367-3>.
- Hauptmann, A., Rehren, Th. and Pernicka, E., 1995. The Composition of Gold from the Ancient Mining District of Verespatak/Roşia Montană, Romania. In: G. Morteani and J.P. Northover, eds. 1995. *Prehistoric Gold in Europe: Mines, Metallurgy and Manufacture*. Dordrecht: Springer Netherlands. pp.369-381. https://doi.org/10.1007/978-94-015-1292-3_24.
- Hoopes, J.W., 2017. Magical Substances in the Land between the Seas: Luxury Arts in Northern South America and Central America. In: J. Pillsbury, T. Potts and K.N. Richter, eds. 2017. *Golden Kingdoms: Luxury Arts in the Ancient Americas*. Los Angeles: J. Paul Getty Museum and Getty Research Institute. pp.55-65.
- Hosler, D., 1995. Sound, Color and Meaning in the Metallurgy of Ancient West Mexico. *World Archaeology*, 27(1), pp.100-115.
- Huston, D.L. and Champion, D.C., 2023. Applications of Lead Isotopes to Ore Geology, Metallogenesis and Exploration. In: D. Huston and J. Gutzmer, eds. 2023. *Isotopes in Economic Geology, Metallogenesis and Exploration, Mineral Resource Reviews*. Cham: Springer International Publishing. pp.155-187. https://doi.org/10.1007/978-3-031-27897-6_6.
- Jones, J. and King, H., 2002. Gold of the Americas. *The Metropolitan Museum of Art Bulletin*, 59(4), pp.1-55.
- Kamenov, G.D., Melchiorre, E.B., Ricker, F.N. and DeWitt, E., 2013. Insights from Pb Isotopes for Native Gold Formation During Hypogene and Supergene Processes at Rich Hill, Arizona. *Economic Geology*, 108(7), pp.1577-1589. <https://doi.org/10.2113/econgeo.108.7.1577>.
- Killick, D., Stephens, J. and Fenn, T.R., 2020. Geological constraints on the use of lead isotopes for provenance in archaeometallurgy. *Archaeometry*, 62(1), pp.1-20. <https://doi.org/10.1111/arcms.12573>.
- Klein, S., Lahaye, Y., Brey, G.P. and von Kaenel, H.M., 2004. The early roman imperial AES coinage II: Tracing the copper sources by analysis of lead and copper isotopes-copper coins of Augustus and Tiberius. *Archaeometry*, 46(3), pp.469-480. <https://doi.org/10.1111/j.1475-4754.2004.00168.x>.

- Klein, S., Rose, T., Westner, K.J. and Hsu, Y.K., 2022. From OXALID to GlobaLID: Introducing a modern and FAIR lead isotope database with an interactive application. *Archaeometry*, 64(4), pp.935-950. <https://doi.org/10.1111/arc.12762>.
- Knight, J.B., Morison, S.R. and Mortensen, J.K., 1999. The relationship between placer gold particle shape, rimming, and distance of fluvial transport as exemplified by gold from the Klondike District, Yukon Territory, Canada. *Economic Geology*, 94(5), pp.635-648. <https://doi.org/10.2113/gsecongeo.94.5.635>.
- Lafleur, P.J., 2006. *Technical Report for the Crucitas Project of Vannessa Ventures Ltd, Calgary*. Calgary.
- Lange, F.W. and Accola, R.M., 1979. Metallurgy in Costa Rica. *Archaeology*, 32(5), pp.26-33.
- Lechtman, H., 1984. Pre-Columbian Surface Metallurgy. *Scientific American*, 250(6), pp.56-63.
- Lothrop, S.K., 1937. *Coclé: An Archaeological Study of Central Panama, Part I: Historical Background, Excavations at the Sitio Conte, Artifacts and Ornaments*. Cambridge: Peabody Museum Press.
- Lothrop, S.K., 1963. *Archaeology of the Diquís Delta, Costa Rica*. Papers of the Peabody Museum of Archaeology and Ethnology, Harvard University Volume, 51. Cambridge: Peabody Museum.
- MacCurdy, G.G., 1911. A study of Chiriquian antiquities. *Memiors of the Connecticut Academy of Arts and Sciences*, 3. New Haven: Yale University Press.
- Macfarlane, A.W. and Lechtman, H.N., 2016. Andean Ores, Bronze Artifacts, and Lead Isotopes: Constraints on Metal Sources in Their Geological Context. *Journal of Archaeological Method and Theory*, 23(1), pp.1-72. <https://doi.org/10.1007/s10816-014-9225-8>.
- Mathur, R. and Zhao, Y., 2023. Copper Isotopes Used in Mineral Exploration. In: D. Huston and J. Gutzmer, eds. 2023. *Isotopes in Economic Geology, Metallogenesis and Exploration, Mineral Resource Reviews*. Cham: Springer International Publishing. pp.433-450. https://doi.org/10.1007/978-3-031-27897-6_14.
- Mayo, J., Mojica, A., Ruiz, A., Moreno, E. and Mayo, C., 2007. Estructuras arquitectónicas incipientes y áreas de explotación minera prehispánica de las cuencas de los ríos Grande y Coclé del Sur, Panamá [Incipient architectural structures and pre-Hispanic mining areas of the Grande and Coclé del Sur river basins, Panama]. *Revista Española de Antropología Americana*, 37(1), pp.93-110.
- Meeks, N.D. and Tite, M.S., 1980. The analysis of platinum-group element inclusions in gold antiquities. *Journal of Archaeological Science*, 7(3), pp.267-275. [https://doi.org/10.1016/S0305-4403\(80\)80029-X](https://doi.org/10.1016/S0305-4403(80)80029-X).
- Mixa, P., Dobeš, P., Žáček, V., Lukeš, P. and Quintanilla, E.M., 2011. Epithermal gold mineralization in Costa Rica, Cordillera de Tilarán -exploration geochemistry and genesis of gold deposits. *Journal of Geosciences*, 56(1), pp.81-104.
- Molina Muñoz, P., 2017. *Worldview, symbolism and technology of the indigenous peoples of Costa Rica*. San José: Fundación Museos Banco Central de Costa Rica.
- Nelson, C.E., 2007. Chapter 32: Metallic mineral resources. In: J. Bundschuh and G.E. Alvarado, eds. 2007. *Central America: Geology, Resources and Hazards*. London: Francis and Taylor Group. pp.885-915.
- Numrich, M., Schwall, C., Lockhoff, N., Nikolentzos, K., Konstantinidi-Syvridi, E., Cultraro, M., Horejs, B. and Pernicka, E., 2023. Portable laser ablation sheds light on Early Bronze Age gold treasures in the old world: New insights from Troy, Poliochni, and related finds. *Journal of Archaeological Science*, 149, 105694. <https://doi.org/10.1016/j.jas.2022.105694>.
- Ogden, J.M., 1977. Platinum group metal inclusions in ancient gold artifacts. *Historical Metallurgy*, 11(2), pp.53-72.
- Okamoto, H., Chakrabarti, D.J., Laughlin, D.E. and Massalski, T.B., 1987. The Au-Cu (gold-copper) system. *Journal of Phase Equilibria*, 8(5), pp.454-474. <https://doi.org/10.1007/BF02893155>.
- Quilter, J., 2004. *Cobble Circles and Standing Stones: Archaeology at the Rivas Site, Costa Rica*. Iowa City: University Of Iowa Press.
- Quilter, J. and Hoopes, J.W. eds., 2003. *Gold and Power in Ancient Costa Rica, Panama, and Colombia: A Symposium at Dumbarton Oaks, 9 and 10 October 1999*. Washington D.C.: Dumbarton Oaks Research Library and Collection.
- Redwood, S.D., 2020. The history of mining and mineral exploration in Panama: From Pre-Columbian gold mining to modern copper mining. *Boletín de la Sociedad Geológica Mexicana*, 72(3), A180720. <https://doi.org/10.18268/BSGM2020v72n3a180720>.
- Root, W.C., 1961. 17. Pre-Columbian Metalwork of Colombia and Its Neighbors. In: S.K. Lothrop, ed. 1961. *Essays in Pre-Columbian Art and Archaeology*. Cambridge: Harvard University Press. pp.242-257. <https://doi.org/10.4159/harvard.9780674864917.c19>.
- Rovira, S., 1994. Pre-Hispanic Goldwork from the Museo de America, Madrid: A New Set of Analyses. In: D.A. Scott and P. Meyers, eds. 1994. *Archaeometry of Pre-Columbian Sites and Artifacts. Proceedings of a Symposium organized by the UCLA Institute of Archaeology and the Getty Conservation Institute Los Angeles, California March 23-27, 1992*. The Getty Conservation Institute. pp.323-352.
- Sáenz-Samper, J. and Martínón-Torres, M., 2017. Depletion gilding, innovation and life-histories: the changing colours of Nahuange metalwork. *Antiquity*, 91(359), pp.1253-1267. <https://doi.org/10.15184/aqy.2017.97>.
- Schlosser, S., 2004. *Archäometrische Untersuchungen zur Herstellungstechnik präkolumbischer Goldobjekte aus Costa Rica. Die Funde aus El General / Panteón de la Reina im Ethnologischen Museum Berlin [Archaeometric studies on the production technique of pre-Columbian gold objects from Costa Rica. The finds from El General / Panteón de la Reina in the Ethnological Museum Berlin]*. Diploma thesis Technische Universität Bergakademie Freiberg.
- Scott, D.A., 1995. Goldwork of Pre-Columbian Costa Rica and Panama: A Technical Study. In: P.B. Vandiver, J.R. Druzik, J.L. Galvan Madrid, G.S. Wheeler and I. Freestone, eds. 1995. *Materials issues in art and archaeology IV. Symposium held May 16-21, 1994, Cancun, Mexico*,

Materials Research Society Symposia Proceedings. Pittsburgh: Materials Research Society. pp.499-526.

Shimada, I. and Craig, A.K., 2013. The Style, Technology and Organization of Sicán Mining and Metallurgy, Northern Peru: Insights from Holistic Study. *Chungará, Revista de Antropología Chilena*, 45(1), pp.3-31. <https://doi.org/10.4067/S0717-73562013000100001>.

Snarskis, M.J., 1985. Symbolism of Gold in Costa Rica and Its Archaeological Perspective. In: J. Jones, ed. 1985. *The Art of Precolumbian Gold. The Jan Mitchell Collection*. New York: The Metropolitan Museum of Art. pp.22-33.

Snarskis, M.J., 2003. From Jade to Gold in Costa Rica: How, Why and When. In: J. Quilter and J.W. Hoopes, eds. 2003. *Gold and Power in Ancient Costa Rica, Panama, and Colombia. A symposium at Dumbarton Oaks 9 and 10 October 1999*. Washington D.C.: Dumbarton Oaks Research Library and Collection. pp.159-204.

Soto, G.J., 2011. Metal mining in Central America (early 1500s-late 1800s). In: J.E. Ortiz, O. Puche, I. Rábano and L.F. Mazadiego, eds. 2011. *History of Research in Mineral Resources, Cuadernos del Museo Geominero*, 13. Madrid: Instituto Geológico y Minero de España. pp.89-97.

Stöllner, Th., 2003. Mining and Economy – A Discussion of Spatial Organisations and Structures of Early Raw Material Exploitation. In: Th. Stöllner, G. Körlin, G. Steffens and J. Cierny, eds. 2003. *Man and Mining. Studies in honour of Gerd Weisgerber. Der Anschnitt, Beiheft*, 16. Bochum: Deutsches Bergbau-Museum Bochum. pp.415-446.

Stone, D., 1961. 13. The Stone Sculpture of Costa Rica. In: S.K. Lothrop, ed. 1961. *Essays in Pre-Columbian Art and Archaeology*. Harvard University Press. pp.192-209. <https://doi.org/10.4159/harvard.9780674864917.c15>.

Stone, D. and Balsler, C., 1965. Incised Slate Disks from the Atlantic Watershed of Costa Rica. *American Antiquity*, 30(3), pp.310-329. <https://doi.org/10.2307/278811>.

Tosdal, R.M., Wooden, J.L. and Bouse, R.M., 1999. Pb Isotopes, Ore Deposits, and Metallogenic Terranes. In: D.D. Lambert and J. Ruiz, eds. 1999. *Application of Radiogenic Isotopes to Ore Deposit Research and Exploration, Reviews in Economic Geology*. Littleton: Society of Economic Geologists. pp.2-28. <https://doi.org/10.5382/Rev.12.01>.

Townley, B.K., Hérail, G., Maksiyev, V., Palacios, C., Parseval, P. de, Sepulveda, F., Orellana, R., Rivas, P. and Ulloa, C., 2003. Gold grain morphology and composition as an exploration tool: application to gold exploration in covered areas. *Geochemistry: Exploration, Environment, Analysis*, 3(1), pp.29-38. <https://doi.org/10.1144/1467-787302-042>.

Tripcevich, N. and Vaughn, K.J. eds., 2013. *Mining and Quarrying in the Ancient Andes: Sociopolitical, Economic, and Symbolic Dimensions*. Interdisciplinary Contributions to Archaeology. New York: Springer New York. <https://doi.org/10.1007/978-1-4614-5200-3>.

United States Geological Survey, 1987. *Mineral resource assessment of the Republic of Costa Rica*. Miscellaneous Investigations Series Map I-1865. USGS.

Authors

Guntram Gassmann
Independent Researcher (Company ARGUs)
Kastellweg 10
42042 Tübingen, Germany
argus.gassmann@t-online.de

Sabine Klein
Ruhr-Universität Bochum
Institut für Archäologische Wissenschaften
and
Deutsches Bergbau-Museum Bochum
Forschungsbereich Archäometallurgie
Am Bergbaumuseum 31
44791 Bochum, Germany
Sabine.Klein@bergbaumuseum.de
ORCID: 0000-0002-3939-4428

Andreas Schäfer
Ur- und Frühgeschichtliche Archäologie
Otto-Friedrich-Universität Bamberg
Institut für Archäologische Wissenschaften,
Denkmalwissenschaften und Kunstgeschichte
Am Kranen 14
96045 Bamberg, Germany
andreas.schaefer@uni-bamberg.de

Elias Welk
Ur- und Frühgeschichtliche Archäologie
Otto-Friedrich-Universität Bamberg
Institut für Archäologische Wissenschaften,
Denkmalwissenschaften und Kunstgeschichte
Am Kranen 14
96045 Bamberg, Germany
elias-nathanael.welk@stud.uni-bamberg.de

Katrin Westner (Corresponding author)
Deutsches Bergbau-Museum Bochum
Forschungsbereich Archäometallurgie
Am Bergbaumuseum 31
44791 Bochum, Germany
Katrin.Westner@bergbaumuseum.de
ORCID: 0000-0001-5529-1165