

Do Plundered Tombs Still Speak? Archaeometric Evidence from the Pre-Hispanic site of Siete Ventanas de Cochapetí, Peru

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Abstract

Chullpas are among the most distinctive and culturally significant architectural structures associated with funeral rites in the central Andes. This paper summarises archaeological research at the multi-chamber *chullpa* of Siete Ventanas de Chochapeti, which, despite having been emptied many years earlier, preserves evidence that contributes to the reconstruction of metal production processes and the identification of ore sources. Materials science analysis of fragments of two copper artefacts and two silver artifacts indicates variation in the production of individual metals. The copper artefacts were only cast, while the silver artefacts were also forged to varying degrees of sophistication. Lead isotope results obtained for the silver artefacts indicate that the ore source was most likely the Cerro de Pasco deposit, or one of several deposits. The presented results show that geochemical examination of *chullpa* artefacts can provide a lot of new data to determine the socio-economic and cultural connections of different cultures.

1. Introduction

Above-ground funerary structures conventionally described as *chullpas* constituted an important cultural and social element of the pre-Columbian Central Andes [1, 2, 3, 4]. Spatially, they could form larger ceremonial or funerary complexes [5, 6, 7, 8, 9, 10], or dotted mountainous landscapes as individual, separate structures [9, 10, 11, 12, 13]. Regardless of location, *chullpas* were built to resemble human dwellings but to shelter human remains, often those of members of a particular *ayllu*, a kinship-based group and the primary unit of Andean social organisation. [14]. Therefore, *chullpas* were designed to permit recurrent access and frequently served as focal places for recurrent mortuary practices, ancestor veneration, and the maintenance of social memory [2, 3, 4, 6, 10]. The relative visibility in the landscape and easy access also meant that many *chullpas* had been robbed, often multiple times, or emptied during unprofessional excavations [15].

The *chullpas* are found all over the mid- and high-altitude zones of the western Andean slopes [16] and are especially prominent in the highlands of the modern Áncash department in north-central Peru. Most archaeological projects investigating *chullpa*-related sites have focused primarily on their spatial organisation and landscape setting [6, 7, 9, 10, 11, 13, 17, 18], architecture [5, 6, 7, 8, 9, 10, 12, 13], bioarchaeological analyses of human and animal remains buried within them [9, 10, 13, 19, 20, 21], and typological or stylistic analysis of associated artefacts [5, 6, 8, 10, 12], including metal objects.

Metal objects have been documented in a few Áncash *chullpas*. For example, the Middle Horizon (600–1000 CE) *chullpas* excavated at Piquijirca and Pampirca in the intramountainous valley of Callejón de Huaylas contained copper tupus, needles, pendants, and silver objects, providing an earlier regional precedent for the deposition of metal in above-ground funerary structures [5]. More directly relevant to the Late Intermediate Period (1000–1476 CE) and Late Horizon (1476–1534 CE), small, perforated copper discs were recovered from *chullpas* 13 and 26 at Marcajirca, while metal needles or tupus were

also present in site's funerary assemblages [10]. In selected funerary assemblages, objects of copper, silver, and gold therefore constituted socially valued elements deposited with the dead.

Metal objects were also recovered elsewhere in the central Andes; they are well documented in Late Horizon *chullpas* and related funerary contexts, but their composition, technological history, and provenance have rarely been investigated using modern archaeometric methods. A rich assemblage of gold, silver, and copper objects was recovered near the *chullpa* del Lagarto at Sillustani, although the precise stratigraphic relationship between the deposit and the funerary tower remains uncertain [12]. Chemical data for 35 artefacts are reportedly available [22], but comparable isotopic evidence remains extremely limited. Related archaeometric research has applied mercury and sulfur isotope analysis to cinnabar from *chullpa* contexts in the Chincha Valley [23], while beads from a Bolivian *chullpa* funerary assemblage have been examined using a combination of microscopy, spectroscopy, and chemical methods [24]. Such studies demonstrate the potential of archaeometric analyses of materials from *chullpas* contexts, but do not provide data on the raw materials' origin gleaned from isotopic composition of metallic artefacts.

Archaeometric analysis concerning lead isotope are becoming standard practice in research on the provenance of artefacts in archaeology [25, 26, 27, 28, 29, 30, 31]. The use of geological data [32] and the continuous development of new methods for processing and interpreting isotopic data [33, 34] demonstrate that, despite its limitations, this method is one of the most important in determining the source of raw materials. This is evident in both large-scale studies [30, 35] and the analysis of individual artefacts [26, 36, 37], as both help to determine economic connections between individual regions, cultures, and peoples. This is crucial for reconstructing socio-economic and political relations in a given region at a given time.

Still, the lack of widespread isotopic studies of metal objects represents a major gap in our understanding of the distribution of raw materials and, in particular, finished metal products in the Central Andes. Information on the circulation of finished objects could improve understanding of the social, economic, and cultural relationships linking places of ancestor veneration with local and regional communities. Provenance analysis, when combined with metallographic, chemical, and stylistic investigations, may provide further insight into the technological, economic, cultural, and political relationships linking local populations with different regions and societies of the Central Andes. The results of provenance studies may thus help constrain circulation pathways and identify connections among metal sources, production zones, larger sociopolitical centres, and smaller funerary contexts. Similar integrated approaches have already been applied to metal artefacts and metallurgical materials from larger funerary complexes in Áncash, most notably Castillo de Huarmey, an important Wari culture (Middle Horizon) site located in the lower Huarmey River Valley [37, 38, 39, 40, 41].

The Huarmey Valley and the adjacent Culebras Valley contain numerous archaeological sites spanning varied chronologies and functions, including many settlements and cemeteries dating to the Middle Horizon, Late Intermediate Period, and Late Horizon [42, 43, 44]. During the Late Intermediate Period, the

Huarmey–Culebras region was occupied by locally organised coastal communities that participated in the broader Casma material and technological sphere while maintaining connections with neighbouring coastal valleys and the Áncash highlands. In the Culebras Valley, the Late Intermediate Period is represented by the local Ten Ten phase and the development of Casma-related centres and settlements [44]. During the Late Horizon, many existing Casma sites were adapted or transformed following their incorporation into the Inca system, while important elements of local occupation and material practices continued [44]. However, although published regional prospections of archaeological sites record numerous cemeteries along the Huarmey–Culebras transect from the coast to the highlands, to date *chullpa*-type funerary architecture and its associated assemblages remain poorly documented.

The Siete Ventanas site—Spanish for “seven windows”—is located about 8 km west of a modern village, Cochapetí, in the highlands of Huarmey Province, at an elevation of about 2,900 m a.s.l. (Fig. 1). The *chullpa* sits on a narrow rock shelf bound by near-vertical bedrock faces and offers a westward view across the valley (Fig. 2). Its façade contains seven chamber openings arranged across multiple levels. The chamber configuration indicates at least three construction episodes. The earliest phase comprised three burial chambers. A two-chamber section was later added to the right when viewed from the front, and two smaller chambers were subsequently built above the earlier units (Fig. 3). This multi-stage arrangement places Siete Ventanas within the broader tradition of collective above-ground funerary architecture documented in the Áncash highlands.

By the time of our 2025–2026 archaeological campaign, the *chullpa* had been repeatedly disturbed, and much of its original funerary assemblage had been removed. A local historical account records the extraction of funerary bundles, textiles, bone flutes, ceramic vessels, and gold and silver ornaments, some of which were reportedly transferred to a school museum in Cochapetí, which was destroyed in the 1970 earthquake [45, 46]. The condition of the site observed during the 2025–2026 season therefore resulted from a long sequence of funerary use, reopening of the chambers, natural exposure, looting, and undocumented removal of archaeological materials.

The 2025–2026 campaign combined architectural recording, UAV and close-range photogrammetry, and the excavation and sieving of deposits preserved within the seven chambers and on the small platform in front of the structure. Although no intact burial assemblages survived, the residual and redeposited deposits contained commingled human remains, a small faunal assemblage, and fragments of archaeological objects, including the four metal fragments examined in this study. Their general findspots are shown in Fig. 3. The analytical value of these materials does not depend on their association with an undisturbed burial. Instead, the documented recovery context, taphonomic evidence, and archaeometric analyses make it possible to reconstruct selected aspects of the *chullpa*’s depositional history and the technological and geographical histories of objects once deposited there.

Figure 1. Location map of the Siete Ventanas de Cochapetí site, Peru.

Figure 2. 3D model of the Siete Ventanas Chullpa and surrounding cliff face. The main view displays the terrain model generated from UAV photogrammetry. The inset (top left) provides a high-resolution close-

up of the Chullpa structure derived from close-range photogrammetry.

Figure 3. Architectural documentation of the Siete Ventanas Chullpa displaying top plan, front elevation, and side profile views, with general findspots of metal artefacts.

Bioarchaeological analysis of the human osteological material recovered from the seven chambers of the *chullpa* and from the stratigraphic deposits of the small platform in front of the structure provides insight into both the formation history of the assemblage and the individuals associated with the funerary context. The skeletal remains are highly fragmented and lack preserved anatomical associations, while observed weathering stages indicate repeated exposure to environmental conditions. Small bones—including manual and pedal phalanges, carpals, tarsals, metacarpals, and metatarsals—are the most frequently represented elements, followed by vertebrae and fragmented long bones; maximum-length measurements could be obtained only rarely. Together, these observations indicate a prolonged and complex taphonomic history that began with primary deposition and was followed by disarticulation, dislocation, variable exposure, probable reburials, and resulted in extensive commingling. This interpretation is consistent with a relatively recent account documenting one of the latest disturbances, when students from a local school, led by their teacher, visited the site and removed from the tomb *“funerary bundles containing embalmed mummies, covered with finely structured cloths woven with cotton threads. Beside each bundle, bone quenpas, ceramic vessels containing quinoa, and some gold and silver ornaments were found. The women’s hair and the men’s intact teeth were astonishing. They were taken to the town of Cochapetí, where a School Anthropological Museum was created, which was reduced to dust by the earthquake of 1970”* [45, 46].

The fragmented and commingled condition of the assemblage directly affects estimates of the minimum number of individuals. When the chambers and platform are analysed as discrete depositional contexts, the material represents at least 38 individuals: 17 subadults, predominantly very young children, and 21 adults, including a minimum of five males and three females. Given the documented disturbance and taphonomic complexity, however, this estimate should be treated with caution. If the assemblage is considered as a single commingled context, it represents at least six adults and seven children. Paleopathological observations further indicate that pathological changes were most frequent in the dentition, lumbar vertebrae, and joints, whereas healed trauma and other changes like a small mandibular osteoma were recorded only sporadically. Overall, the postdepositional history of the remains limits more detailed individual-level interpretation, but the assemblage nevertheless provides some evidence for demographic composition, taphonomic history, and patterns of pathological change within the funerary context.

Zooarchaeological analyses of the scarce faunal remains recovered through excavation and sieving from deposits within the chullpa's niches and a platform immediately in front of the structure (NISP = 25; see Supplementary Materials 1 for detailed data) were conducted following the methods outlined in Tomczyk et al. [47]. The analyses indicated that all specimens except one, a very young camelid ulna, were most likely accumulated through taphonomic rather than cultural processes. Taxonomically, the

assemblage comprised taxa typical of the Andean highlands: Andean fox (*Lycalopex culpaeus*), deer (either white-tailed deer (*Odocoileus virginianus*) or taruka (*Hippocamelus antisensis*)) and microfauna, including rodents and bats that could not be identified to species level. The latter taxa are known to colonise infrequently visited *chullpas* [6, 21]. In contrast, the camelid ulna most likely represents an archaeological food offering, deemed not important during earlier excavations. Because camelids have been virtually absent from the mid-valleys of northern Peru since colonial times [48], the specimen is unlikely to derive from recent natural deposition.

This article summarises archaeological research at the *chullpa* known as Siete Ventanas de Cochapetí, with particular emphasis on the metal artefacts documented there. We initiate a discussion of the provenance of metals recovered from *chullpa*-type funerary contexts by analysing fragments of metal artefacts collected recently during PRIACH archaeological investigations in the region. The material will be subjected to materials-science analysis using electron microscopy and to the measurement of Pb-isotope ratios using state-of-the-art isotope analytical techniques. The results will be used to reconstruct aspects of metallurgical processes, assess the possible composition and nature of the ores, and, above all, determine the source of the ore used to produce the analysed metals.

This first step, combined with future research, will contribute to the reconstruction of connections among mining areas, production centres, sociopolitical and economic centres, and even the smallest places of ancestor veneration located in the Andean mountain landscape.

2. Methodology and samples

Four samples of metal artefact fragments from the Siete Ventanas de Cochapetí tomb were selected for study: two copper samples (PRIACH_M-3, PRIACH_M-4) and two silver samples (PRIACH_M-1, PRIACH_M-2) (Fig. 4). Small fragments (max. 5/5/1 mm) were taken from each sample. Subsequently, the fragments were divided into three equal parts. One part was designated for chemical and materials science analyses, the second for Pb isotope analyses, and the last for archiving. Chemical and materials science analyses were performed using a scanning electron microscope with Energy-Dispersive X-ray Spectroscopy and Field Emission (FE-SEM-EDS) and an electron microprobe (EPMA). Isotopic analysis was performed using a Multicollector-Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS).

In the absence of directly comparable Late Intermediate Period or Late Horizon *chullpa* assemblages, the monumental Middle Horizon complex at Castillo de Huarmey provides the closest local archaeometric reference. Although Castillo de Huarmey likely predates the use of Siete Ventanas de Cochapetí and represents a fundamentally different, imperial-scale mortuary complex, its metal assemblage offers comparative evidence for examining the circulation and technological history of metals in the Huarmey region [37, 38, 39, 40, 41].

Figure 4. Photos of metal samples from the Siete Ventanas de Cochapetí tomb.

2.1. Chemical and surface analysis using a field emission scanning electron microscope with energy-dispersive X-ray spectroscopy

First, chemical analyses of the sample surfaces and fracture points were performed. For this purpose, the test samples were adhered to an aluminium table with graphite tape. Chemical analyses were performed both point-wise and area-wise. Next, a specimen was prepared from the test samples by placing them in a 1-inch disc and pouring resin (araldite). The specimens were positioned to allow for cross-sectional analysis of the sample surface. The prepared specimen was then ground and polished to a $\frac{1}{4}$ μm grit with diamond paste. Such preparations are crucial for reliable chemical and technological analysis in micro-scale [49]. This enabled the observation of microstructural characteristics and variations in chemical composition. The specimen was then coated with graphite and adhered to an aluminium table with graphite tape. The samples were examined under SEM FE - SIGMAVP (Carl Zeiss Microscopy GmbH) with an EDS detector (Quantax XFlash 3|10, Bruker Nano GmbH).

Analyses were performed with a 120 μm aperture and 20kV acceleration voltage. The beam intensity was 2.5 nA. Working distance depended on the sample height and was chosen to achieve about 7.6mm. The point EDS analysis was performed with a 15s counting time at each point. Such low time needed for analysis was made possible due to a field-emission gun mounted in the FE-SEM. During measurements, the microscope maintained > 100000 counts/s. The same parameters were used for both loose samples (attached with carbon tape) and samples placed in a 1-inch disc. The specimen (1-inch sample disc) was coated with a 20 nm thick carbon layer using a vacuum coating device (Quorum 150 TES).

2.2. Chemical analysis using electron probe microanalysis

The prepared 1-inch preparation was dusted with graphite and placed in a suitable holder. The chemical composition of the main phases and chemical mapping in the studied metal samples were analysed using EPMA (CAMECA SX-100). The analysis was performed at the Electron Microprobe Laboratory Joint-Institute Analytical Complex for Minerals and Synthetic Substances at the Faculty of Geology, University of Warsaw. Analysis by EPMA was performed using a 15 keV accelerating voltage and a 10 nA probe current with a beam size of 5 μm or less, depending on the alloy or mineral/chemical phase being analysed. It is worth noting that during the analysis, the oxygen content was determined by measurement and not added to the computer software.

2.3. Isotope analyses

2.3.1. Sample preparation

Each sample was cleaned of corrosion using diamond-tipped microtools. Such prepared samples were then sent for chemical preparation to the CNBCh UW (Centre for Biological and Chemical Research, University of Warsaw), starting with decomposition in a closed-vessel microwave-assisted

decomposition system (Millipore, Ethos Up). All used reagents were of analytical reagent grade. Nitric acid and hydrogen peroxide (4:1, v/v) were used as the decomposing mixture. A closed system was used to reduce the risk of contamination. Hydrogen peroxide was added to reduce the risk of incomplete sample dissolution. After cooling, the solution was transferred to a test tube and diluted with deionised water (Milli-Q Integral 3 Q-POD Water Purification System, Merck Millipore, Germany). After the dissolution procedure, an aliquot of the solution was analysed by quadrupole ICP-MS (NexION 300D, PerkinElmer, Waltham, MA, USA) for Pb content. Due to the low Pb level, the solutions were sent to a laboratory with increased purity (Clean Lab) for lead extraction from the samples.

2.3.2 Methodology of lead extraction

Samples were evaporated to dryness and then redissolved in 4 ml of 2M HCl. Lead separation was performed using chromatographic columns packed with ion-exchange resin (Bio-Rad AG 1-X8, 200–400 mesh, chloride form). Before use, the columns were cleaned three times using ultrapure water and 6M HCl. The columns were then conditioned in 2M HCl for 30 minutes. Sample solutions were applied to the resin beds and allowed to pass through the columns. The resin beds were washed twice with 1.5 ml of 2M HCl. Lead was eluted four times with 1 ml of 6M HCl, and the eluates were combined. The eluate was evaporated to dryness and reconstituted with 4 ml of 1% HNO₃. All chemical procedures were performed in a clean laboratory at the U-series Laboratory of the Institute of Geological Sciences of the Polish Academy of Sciences (PAN).

2.3.3 Analysis of Pb isotope ratios

Pb isotope ratio analysis was performed at the CNBCh UW. An MC-ICP-MS (Plasma 3, Nu Instruments, Wrexham, UK) device was used for this purpose. An internal standard (TI NIST 997) was used during the analysis. To assess the accuracy of the results, the NIST SRM 981 standard was measured. The results obtained for the NIST SRM 981 standard were compared with literature data [50]. This served to correct the results obtained for the tested samples. Lead isotope analyses were performed in dry plasma mode using an Aridus 3 desolvation nebuliser (Cetac, Omaha) as the sample introduction method.

The results were compared with similar results obtained for ore, rock, and artifact samples from Argentina, Bolivia, Chile, Colombia, Ecuador, and Peru that are recorded in the PANGAEA database [51, 52] and data published in scientific articles [27, 30, 36, 37, 40, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 94, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134]. The comparison was made using two methods. First, comparison diagrams were used (²⁰⁸Pb/²⁰⁴Pb to ²⁰⁶Pb/²⁰⁴Pb; ²⁰⁸Pb/²⁰⁴Pb to ²⁰⁷Pb/²⁰⁴Pb; ²⁰⁸Pb/²⁰⁴Pb to ²⁰⁷Pb/²⁰⁴Pb). The second method was to calculate the Euclidean distance. The general formula for calculating the Euclidean distance is [135]:

$$d(p,q)=\sqrt{((p_1-q_1)^2+(p_2-q_2)^2+\dots+(p_n-q_n)^2)}$$

Where:

d – distance;

p, q - points between which the distance is calculated;

p1, q1, ..., pn, qn - values of Cartesian coordinates for each point in the individual Euclidean spaces.

Distances in three-dimensional space were calculated. The obtained data were used to attempt to determine the source of the ore used to produce the Siete Ventanas de Cochapetí sample. When using Euclidean distance, we consider this metric a screening tool. It aids in ranking potential matches within the available comparative dataset. It is not intended as a standalone proof of provenance. Because Pb isotope ratios are not fully independent and reference datasets differ in analytical precision, distance-based rankings are interpreted in conjunction with (i) visual clustering in bivariate plots, (ii) geological probability (lead isotope provinces), (iii) mineralogical and chemical properties of the analysed material, and (iv) archaeological data associated with a given location. This multicriteria approach reduces the risk of overinterpreting numerical proximity when different deposits may share overlapping isotopic fields. Where possible, reported analytical uncertainties were qualitatively considered when evaluating boundary matches. However, most older datasets do not provide fully comparable uncertainty estimates, which limits uniform calculations of error-weighted distances. Detailed information on locations, diagrams and results can be found in Supplementary Material 2.

3. Results

All raw results are published in Supplementary Materials 2 and 3.

3.1. Chemical analysis

The averaged results of chemical analyses performed using EPMA and FE-SEM_EDS are included in Tables 1 and 2, respectively. Based on the results of chemical analyses (Tables 1 and 2), it is evident that artefacts PRIACH_M-3 and PRIACH_M-4 are made of very pure copper, without significant alloying additions. Artefacts PRIACH_M-1 and PRIACH_M-2 were made of a silver alloy with an addition of copper (approximately 2.5–4 wt%).

Table 1. Averaged results of chemical analyses obtained from EPMA for metal samples from Siete Ventanas de Cochapetí.

Table 2. Averaged results of chemical analyses obtained from FE-SEM-EDS for metal samples from Siete Ventanas de Cochapetí.

Comparing the chemical composition of artefacts from Siete Ventanas de Cochapetí with those from Castillo de Huarmey [38, 39], the closest large collection of metal artefacts reveals certain similarities and differences (Fig. 5). Both copper samples (PRIACH_M-3 and PRIACH_M-4) are practically pure copper without any alloying additives. Such alloys (M24 and M40–40] are also found at Castillo de Huarmey (Fig. 4A). This may indicate a similar type of ore. It was probably pure oxide, hydroxide,

carbonate, or sulfide ore (using roasting). This is evidenced by the lack of admixtures of elements such as As in both the alloy and the pores. The remaining samples from Castillo de Huarmey exhibit significantly higher As concentrations than the tested samples.

In the case of silver samples (PRIACH_M-1 and PRIACH_M-2), only sample PRIACH_M-1 shows similarity in chemical composition to the samples from Castillo de Huarmey (M46A, M46B, M46C, M46D – 40] (Fig. 5B). Sample PRIACH_M-2 has a higher copper content. However, despite the similarity in the alloy's chemical composition, sample PRIACH_M-1 has a completely different composition of the pores contained in the alloy. In sample PRIACH_M-1 (and PRIACH_M-2), the pores are composed mainly of Ag, Cu, and O, while in samples from Castillo de Huarmey, the pore filling consists of Pb, Bi, Ag, Cu, As, and S. This may indicate that either native silver was used and mixed with copper, or some simple silver ores (e.g., sulfides, chlorides) containing no other metals were used to produce the examined artefacts.

Figure 5. Comparison of the chemical composition of the main elements of the tested samples with metal samples from Castillo de Huarmey [38, 39]. A – comparison of copper samples; B – comparison of silver samples.

3.2. Isotope analysis

The results of the isotope analyses are presented in Table 3. The tested samples showed very low lead concentrations (between < 10 and 150 ppm). For the copper samples, the concentration was too low (< 10 ppm) to perform isotope analyses. For the silver samples, the Pb isotope results are as follows: PRIACH_M-1– $^{206}\text{Pb}/^{204}\text{Pb} = 18.799$, $^{207}\text{Pb}/^{204}\text{Pb} = 15.689$ and $^{208}\text{Pb}/^{204}\text{Pb} = 38.111$; PRIACH_M-2– $^{206}\text{Pb}/^{204}\text{Pb} = 18.738$ – 18.739 , $^{207}\text{Pb}/^{204}\text{Pb} = 15.690$ – 15.650 and $^{208}\text{Pb}/^{204}\text{Pb} = 39.736$ – 39.738 . For the PRIACH_M-2 sample, the range of values places it on the borderline between Province I, Province II, and Province III [78, 107]. The PRIACH_M-1 sample clearly indicates Province III [78, 107].

Comparing the obtained data with samples from Castillo de Huarmey [40] (Fig. 5), we see a good match of the PRIACH_M-2 sample to samples M22, M25, M40, and M43, and a good match to samples M26, M27, and M44. The PRIACH_M-1 sample has no match to the Castillo de Huarmey samples. Comparing the obtained results to other results for artefacts from the Middle Horizon from South America (Fig. 6), we see a single good match of the PRIACH_M-2 sample to artefacts from San Pedro de Atacama (1 match) and Conchopata (3 good matches and 5 average matches) [30]. The PRIACH_M-1 sample has only one average match to the Batanes del Tablazo sample [36].

Comparing the obtained results to data published for ores and rocks from the Central Andes area, single good matches are visible (Fig. 7). For PRIACH_M-1, good matches are visible to the following locations: Argentina (Taca-Taca [30]), Bolivia (Sucre [107]), Peru (Cerro de Pasco [53]). Good matches are seen for PRIACH_M-2 with the following locations: Argentina (Bajo de Agua Tapada, Bajo de la Alumbra, Farallon Negro Regional [115], Meseta Chica [91]), Bolivia (Eskapa, Koholpani, Puka Mokho [30]), Chile (Aguas Blancas, Chaco [97], Cerro Galan [59], Lascar [88], Llullaillacu [110], Salar de la Isla [101], Socompa, Ocoña, San Pedro San Pablo [117], Unnamed [122]), Peru (Batanes del Tablazo [36], Cailloma

District, Manta Tuff, Sarpane Volcanics [93], Cercapuquio, Feficidacl, Morocochoa [76], Department Junin [73], Hualgayoc Area [80], Ilo area pluton [57], S. Pichacane [116].

Table 3. Average results of isotopic analyses of the analysed metal samples from Siete Ventanas de Cochapetí.

Figure 6. Comparison of Pb isotope results of the tested samples with literature data for other artefacts from Bolivia, Chile and Bolivia [27, 30, 36, 37, 40].

Figure 7. Comparison of Pb isotope results of the tested samples with literature data for deposits and rocks from the Central Andes area [27, 30, 36, 37, 40, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 94, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134].

3.3 Surface analysis

The surfaces of samples PRIACH_M-3 and PRIACH_M-4 have very similar characteristics. Both samples have a clearly porous and cracked surface. Pitting corrosion is visible in many places [136] (Fig. 8). The microscopic image shows a distinct structural gradient – from a relatively more compact metallic core to a highly developed, porous layer of corrosion products (Fig. 8). This zonation is characteristic of copper in an aggressive environment (presence of Cl⁻, OH⁻, O₂⁻ ions), where successive corrosion of the material progresses [137]. The lack of traces of plastic deformation confirms that the material was not subjected to secondary mechanical processing and retained its as-cast structure.

PRIACH_M-1 and PRIACH_M-2 samples exhibit a highly developed, rough corrosion surface (Fig. 8). The surface structure is heterogeneous, with both relatively smooth areas and highly porous zones visible, with a granular and occasionally cracked texture. Overall, the samples represent heavily corroded artefact fragments made of an Ag–Cu alloy. The surface has been reshaped by long-term exposure to the soil environment. Elevated chlorine and oxygen content indicates intense corrosion processes. Local galvanic cells associated with the presence of copper in the alloy are also present.

A detailed report of the surface analysis can be found in the Supplementary Material 4.

Figure 8. SEM-BSE images of the surface of metal samples: A – PRIACH_M-3; B – PRIACH_M-4; C – PRIACH_M-1; D – PRIACH_M-2.

3.4 Metallographic analysis

BSE images of samples PRIACH_M-3 and PRIACH_M-4 (Fig. 9) show homogeneous microstructures with bright contrast, characteristic of very pure copper. The background is relatively smooth and devoid of distinct phase differences, indicating the absence of alloying elements and high purity of the material. Analysis of the BSE background region of the sample revealed an almost perfectly pure chemical

composition (Cu: 98.53–99.68 wt%; O: 0.22–0.42 wt%), which clearly indicates highly refined, unalloyed copper.

Numerous, fine, spherical pores with varying diameters (of the order of several micrometres) are observed throughout the volume of PRIACH_M-3 and PRIACH_M-4 samples. These pores are uniformly dispersed (Fig. 9). This is typical of gas porosity formed during metal solidification in the casting process. Their presence suggests limited control of gas content in the liquid metal. Pore formation in copper is associated with the nucleation and growth of gas bubbles during the solidification of the liquid metal [138]. Their chemical composition indicates the presence of copper oxides (Cu: 86.85–88.77 wt%; O: 10.28–10.67) and, in some cases, copper chlorides and/or chlorhydroxides (Cu: 84.27 wt%; O: 9.24 wt%; Cl: 2.54 wt%).

The PRIACH_M-1 sample exhibits a distinct directional texture (Fig. 9). This is manifested by the presence of numerous, parallel, longitudinally arranged thin, linear, and elliptical demixtures or inclusions. This indicates intense plastic deformation of the material, most likely as a result of forging or rolling [139]. The bright background is a high-silver Ag–Cu alloy (Fig. 9). A very fine but clearly defined dispersion of copper-rich phases (darker bands) is observed (Fig. 9). A characteristic feature of the microstructure is strong chemical heterogeneity at the microscale. Local fluctuations in Ag and Cu content occur, from areas clearly richer in Ag (Ag: 96.36 wt%; Cu: 3.38 wt%) to zones relatively richer in Cu (Ag: 94.84 wt%; Cu: 5.29 wt%). This distribution indicates chemical microsegregation, most likely formed during alloy solidification and subsequently elongated and oriented by plastic working. Microsegregation results from component redistribution during dendritic solidification and limited solid-state diffusion [140].

The PRIACH_M-2 sample is characterised by a clearly homogeneous, light grey matrix. Numerous pores with diverse morphology are scattered within it (Fig. 9). The pores are strongly enriched in Cu (Ag: 54.52–57.44 wt%; Cu: 36.19–41.96 wt%; O: 9.73–10.88 wt%). The background is relatively uniform, with no distinct grain boundaries visible in the analysed contrast. This suggests a fine-grained or poorly etched structure of the Ag–Cu alloy. The dominant component is the silver-rich phase (Ag: 97.27–98.09 wt%; Cu: 2.54–2.81 wt%). Uniformly dispersed spherical and ellipsoidal pores are visible, exhibiting local directional orientation. This may indicate subsequent plastic deformation. Chemical analyses indicate chemical homogeneity, indicating a well-melted and mixed alloy. The observed heterogeneities are local (pores, corrosion), not technological. The presence of oxygen and Cu-rich phases near the pores suggests that these areas provided preferential pathways for corrosive agents. The pores and microcracks acted as channels for the transport of moisture and aggressive ions, leading to local selective corrosion, the formation of secondary oxide phases, and, consequently, further weakening of the structure.

A detailed report can be found in the Supplementary Material 4.

Figure 9. SEM-BSE images of cross-sections (1-inch specimen) of metal samples: A – PRIACH_M-3; B – PRIACH_M-4; C – PRIACH_M-1; D – PRIACH_M-2.

4. Discussion

Analysis of the results in terms of production technology indicates that the copper artefacts were most likely cast without subsequent forging. The ore used for their production was very simple (oxides, hydroxides, carbonates, or sulfides). The very low Pb concentration (below the detection limit for MC-ICP-MS) prevented the determination of Pb isotope ratios. A similar problem occurred with sample M24 [40]. In that case, the determined Pb isotope ratios show a very large error due to the too-low Pb concentration. The practically identical chemical composition of the analysed copper samples (PRIACH_M-3 and PRIACH_M-4) with sample M24 [39] and similar problems with Pb isotope analysis (to a lesser extent) may indicate either a very similar ore and production method, or even the same source of the metal. Unfortunately, because the M24 sample has no match to ore and rock samples from the Central Andes, the source of the ore cannot be determined by analogy.

The silver samples (PRIACH_M-1 and PRIACH_M-2) show much greater variation. Two different production methods are visible – PRIACH_M-1 shows very clear traces of additional heat and plastic processing (forging and/or rolling); PRIACH_M-2 shows less obvious traces of additional processing steps. Regarding the ore, both samples were most likely made from the same or very similar ore. The biggest difference is the copper content and lead content. In PRIACH_M-1, the copper content ranges between 3.38 and 5.29 wt%, and the lead content between 0.22 and 0.37 wt%. In PRIACH_M-2, the Cu values range between 2.54 and 2.81 wt%, with lead content close to 0. This likely indicates two different ore sources. It is also possible that because PRIACH_M-1 was subjected to additional processing to increase its resistance, more copper, which also contains more lead, was added than in PRIACH_M-2. This fact can make determining the source of the ore difficult. Isotopic data may also indicate the presence of lead at high isotopic values.

Comparing the results of Siete Ventanas silver with published data [27, 30, 36, 37, 40] shows that sample PRIACH_M-1 composition has no published matches, while sample PRIACH_M-2 has quite a few. The latter has a good match with samples from Castillo de Huarmey (MK22, MK25, M40, MK43) [40], one sample from San Pedro de Atacama [30], and a single sample from Conchopata [30]. Unfortunately, all of these matches are to copper artefacts. Therefore, they cannot be taken as an indicator of the source of the ore, but only as an indicator of the isotopic province from which the fluids forming the silver ore came. By comparing Samples PRIACH_M-1 and PRIACH_M-2 with ore and rock samples [27, 30, 36, 37, 40, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 94, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134] very few ore sources with good PRIACH_M-1 matches are visible (Fig. 10). Analyzing all the matches, the most likely source seems to be Cerro de Pasco in Peru [53]. It has the most matches and is relatively close to the Siete Ventanas de Cochapebí location. However, Cerro de Pasco's data derive from studies conducted several decades ago, and their measurement accuracy, compared to modern techniques, is subject to much greater error. PRIACH_M-2 has many more good matches to published data for ores and rocks. Despite many matches (Fig. 6; Supplementary

Material 2), the most probable matches are to the following locations: Cailloma District, Orcopampa District (Manta Tuff, Sarpane Volcanics) [93], Cercapuquio, Felicidad [76], all within Peru. These are either associated with silver deposits (Cailloma District, Orcopampa District) or data from minerals containing silver (galena) impurities (Cercapuquio, Felicidad). The remaining matches are either to single results, making it impossible to determine whether they are a match to a deposit or to a single sample within a deposit. When more than one match to a given location occurs, these are often rock samples or copper ore samples. In both cases, this only indicates the province, not a specific location within that province.

Figure 10. Map of matches of individual samples to the most probable ore sources.

The analyses of materials recovered at Siete Ventanas de Cochapetí provide complementary information on the funerary population and the metal objects deposited in the *chullpa*. The archaeometric results clarify several aspects of alloy composition and production technology, but the provenance of the metals remains less certain. Rather than indicating a single source, the lead-isotope data identify several possible source regions and highlight the limitations of the available comparative datasets. Resolving these questions will require a broader regional research program that combines analyses of ores, geological materials, and metal objects from securely dated archaeological contexts across the Áncash region. Such research should also consider communication routes, patterns of mobility, and contacts among the communities that connected the coast, river valleys, and highlands. The new research project at Cacuas Jirca, investigating sites likely associated with the production of various goods during the Late Intermediate Period and Late Horizon, offers an important opportunity to develop this regional comparative framework.

Although Castillo de Huarmey should not be treated as a directly comparable source assemblage because it belongs to the Middle Horizon and represents a different chronological and sociopolitical context, its extensive archaeometallurgical record still provides a useful diachronic contrast for the materials from Siete Ventanas. Comparing the two sites may help assess whether metallurgical practices and metal procurement systems established during the Wari period persisted, were transformed, or were replaced by later local communities and polities in the Huarmey and Áncash regions. At present, the observed similarities should therefore be understood as a basis for investigating long-term technological change.

The lack of geochemical data, particularly Pb isotope data, from the LIP and LH currently limits comparing the Siete Ventanas artefact with contemporaneous sites, reducing comparative data to raw ores and rocks. Such a comparison revealed that the metal artefacts found in the *chullpa* came from at least several different locations (Fig. 10). The ore source for PRIACH_M-1 is quite close, as Cerro de Pasco is relatively nearby and is one of the largest polymetallic mines in the region. It could very well be a potential source of ore for the artefact under study. The PRIACH_M-2 sample is more problematic, as its signatures indicate at least two relatively distant regions in the Central Andes. The first is located in the central Peruvian Andes between Lima, Cerro de Pasco, and Huancayo. This region is known for its many polymetallic deposits and lies relatively close to the Siete Ventanas de Cochapetí. However, the

two matching locations in this region are quite far apart. However, they are much closer than the last location (Orcopampa). The distance between *Chullpa* and this location is over 1,500 km. While it was certainly possible to transport finished products over such a long distance [37, 40], given the rich deposits much closer by that provide an equally good match, this seems unlikely, but not impossible.

Each artefact fragment examined was created differently, which may indicate different purposes and/or craftsmanship for the individual items. Unfortunately, due to the artefacts' size and state of preservation, it is difficult to determine their purpose or function beyond ritual and/or ornamentation.

Repeated looting and subsequent disturbance at Siete Ventanas, evidenced by the fragmentary bioarchaeological record and the predominantly intrusive zooarchaeological assemblage, preclude reconstruction of the original associations among individual burials, metal objects, and depositional events. Nevertheless, the surviving metal fragments retain technological and geochemical information that can be examined independently of these lost associations. The analyses presented here characterise selected aspects of manufacture and constrain possible source regions, but they cannot restore the social context in which the objects were originally deposited. Their broader interpretation will require comparative analyses of securely dated metal assemblages and potential ore sources across Áncash.

The Siete Ventanas assemblage illustrates both the potential and the limitations of archaeometric research in a heavily disturbed funerary context. Nevertheless, the four surviving metal fragments retained technological, chemical, and isotopic evidence that could not have been obtained through typological examination alone.

The two copper fragments consist of nearly pure, unalloyed copper and preserve as-cast microstructures, with no evidence of mechanical working after casting. Their very low Pb concentrations precluded reliable lead-isotope analysis. The silver objects record more varied technological histories. PRIACH_M-1 displays extensive thermomechanical processing consistent with forging and annealing, whereas PRIACH_M-2 retains a predominantly cast microstructure. Differences in their Cu and Pb concentrations may reflect different alloying recipes, refining procedures, or histories of metal preparation. Their distinct Pb-isotope signatures further indicate that the two silver objects did not necessarily derive from the same metal supply.

Among the currently available comparative data, PRIACH_M-1 most closely matches deposits in central Peru, including Cerro de Pasco, whereas PRIACH_M-2 overlaps with several datasets from central and southern Peru, including Cailloma, Orcopampa, Cercapuquio, and Felicidad. Because isotope signatures may overlap among deposits and the regional reference database remains uneven, these correspondences identify candidate source regions rather than specific mines. They therefore cannot, by themselves, demonstrate a particular exchange route or the long-distance movement of the objects. The principal contribution of the Siete Ventanas assemblage is to establish a comparative reference for future research on technological change and metal circulation in the Áncash region and beyond. Comparisons with securely dated assemblages and potential ore sources may eventually clarify whether

metallurgical practices established during the Wari period persisted, were reorganised, or were replaced under later local communities and polities.

Declarations

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Author Contribution

AS – main research contractor, sample preparation, sample surface analysis, sample chemical analysis, result interpretation, manuscript preparation, analysis reports; MK – research initiator, study originator, sample preparation for analysis, development and interpretation of results, manuscript preparation, work organization, corresponding author; JK – analysis of Pb isotopes, description of measurement methods; PS – sample preparation in the Clean Lab, description of the sample preparation method; BMM – performing chemical analyses of samples using EPMA; ER – field sampling, sample documentation, drawing preparation; JMC – digital documentation of the site, geolocation, manuscript preparation; PPG – responsible for organizing the excavations, sampling at the archaeological site, archaeological interpretation of the obtained results, and manuscript preparation; WT – zooarchaeological analysis of animal remains, manuscript preparation; RPN – archaeological analysis of the collected material (artifacts); JS – digital documentation of the site, preparation of engravings; JSz – geolocation, preparation of engravings; WW – anthropological analysis of human remains, manuscript preparation; MG – lead archaeologist for the project, responsible for organizing the excavations, sampling at the archaeological site, sample dating, and archaeological analysis of the obtained results.

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Data Availability

The authors declare that the data supporting the findings of this study are available within the paper and its Supplementary Information files. Should any raw data files be needed in another format they are available from the corresponding author upon reasonable request.

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Tables

Table 1 to 3 are available in the Supplementary Files section.

Figures

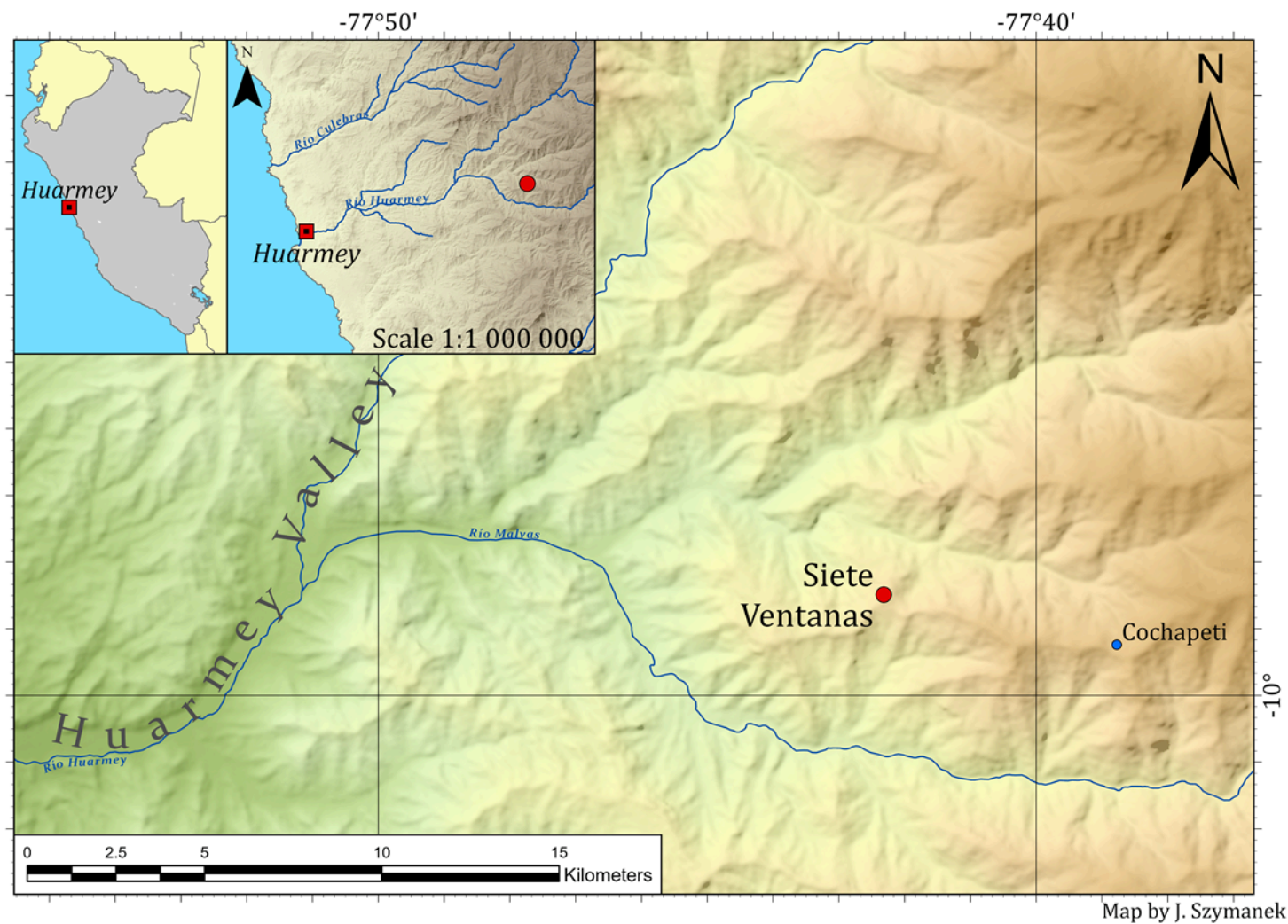


Figure 1

Location map of the Siete Ventanas de Cochapetí site, Peru.

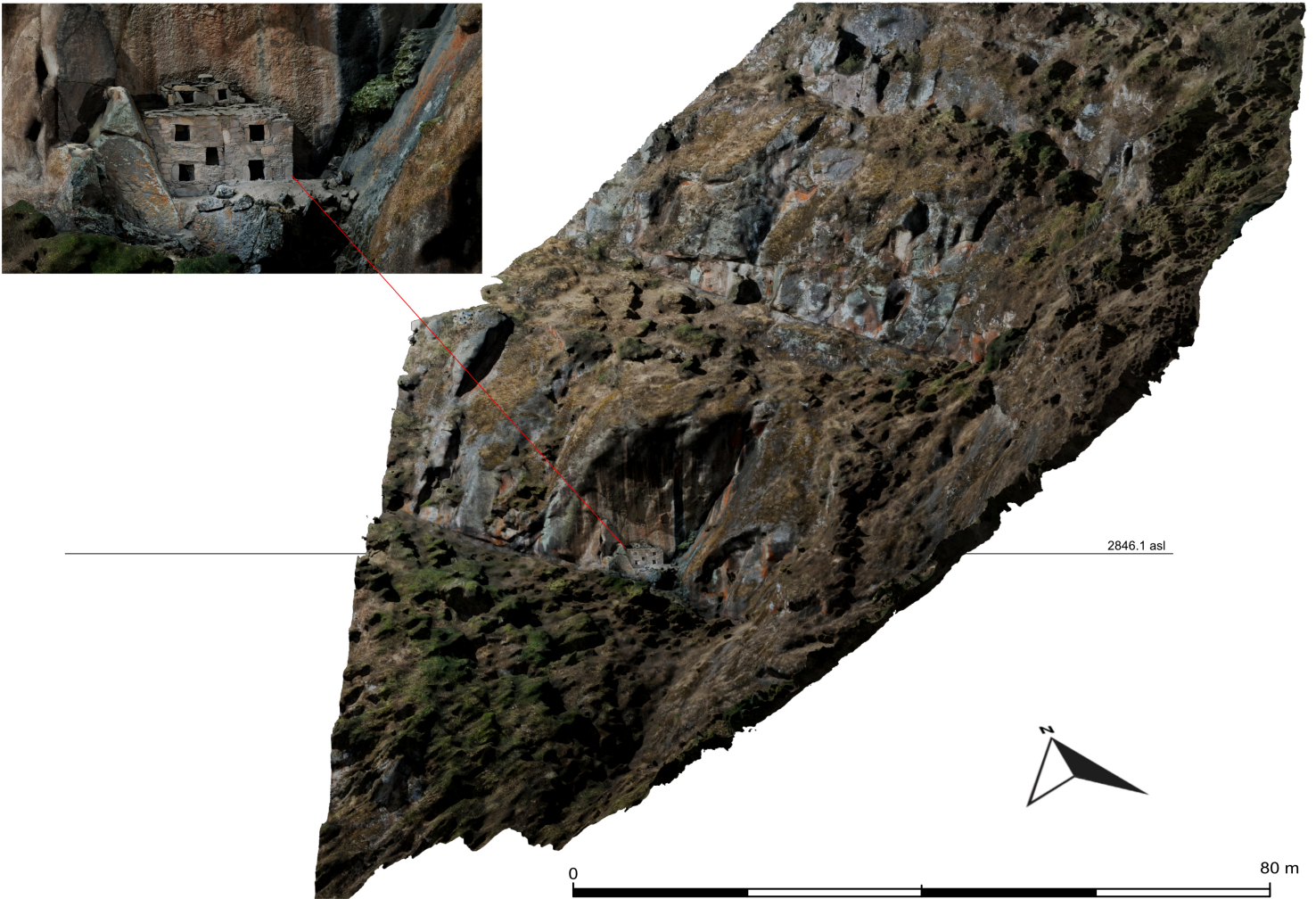


Figure 2

3D model of the Siete Ventanas Chullpa and surrounding cliff face. The main view displays the terrain model generated from UAV photogrammetry. The inset (top left) provides a high-resolution close-up of the Chullpa structure derived from close-range photogrammetry.

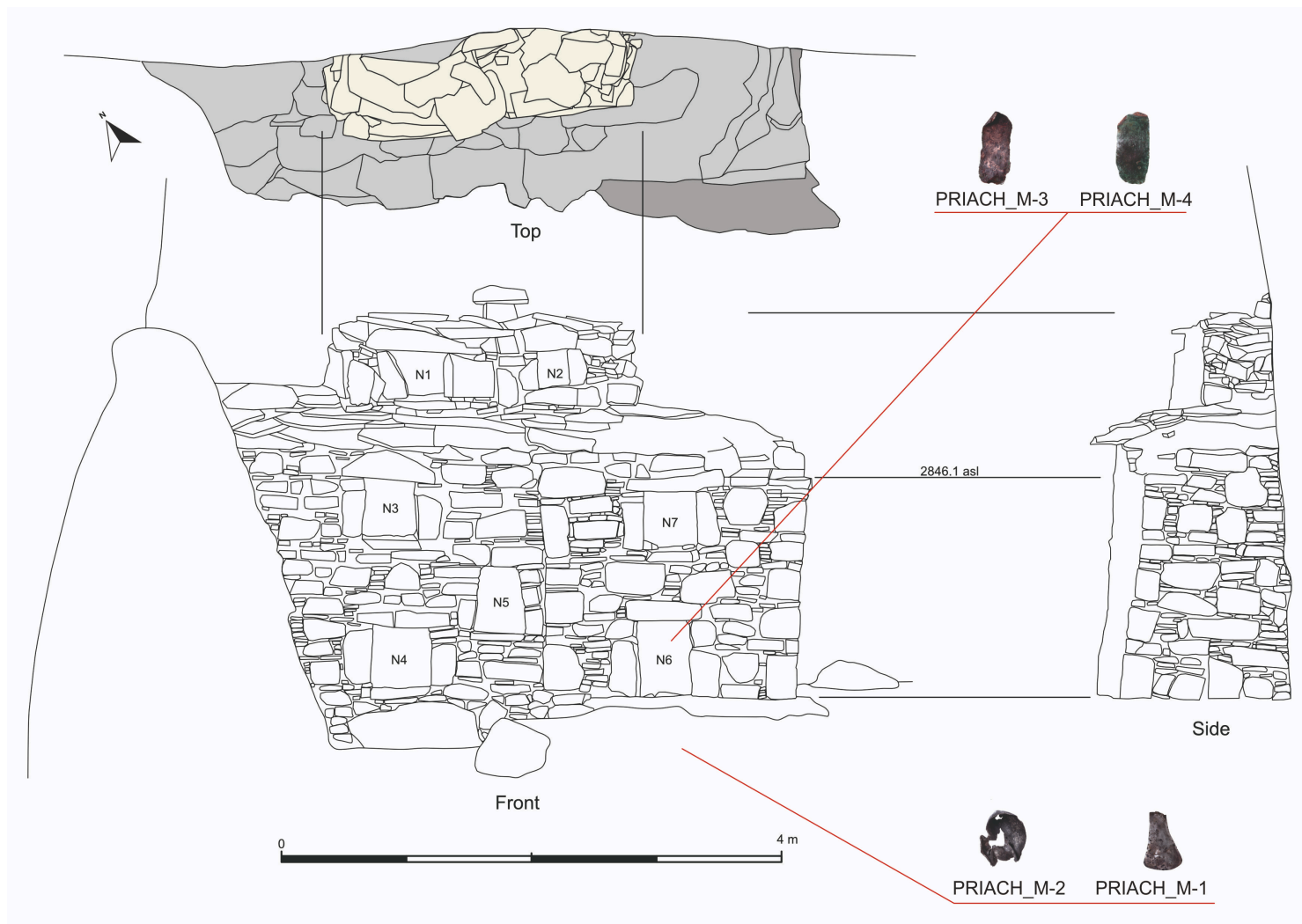


Figure 3

Architectural documentation of the Siete Ventanas Chullpa displaying top plan, front elevation, and side profile views, with general findspots of metal artefacts.

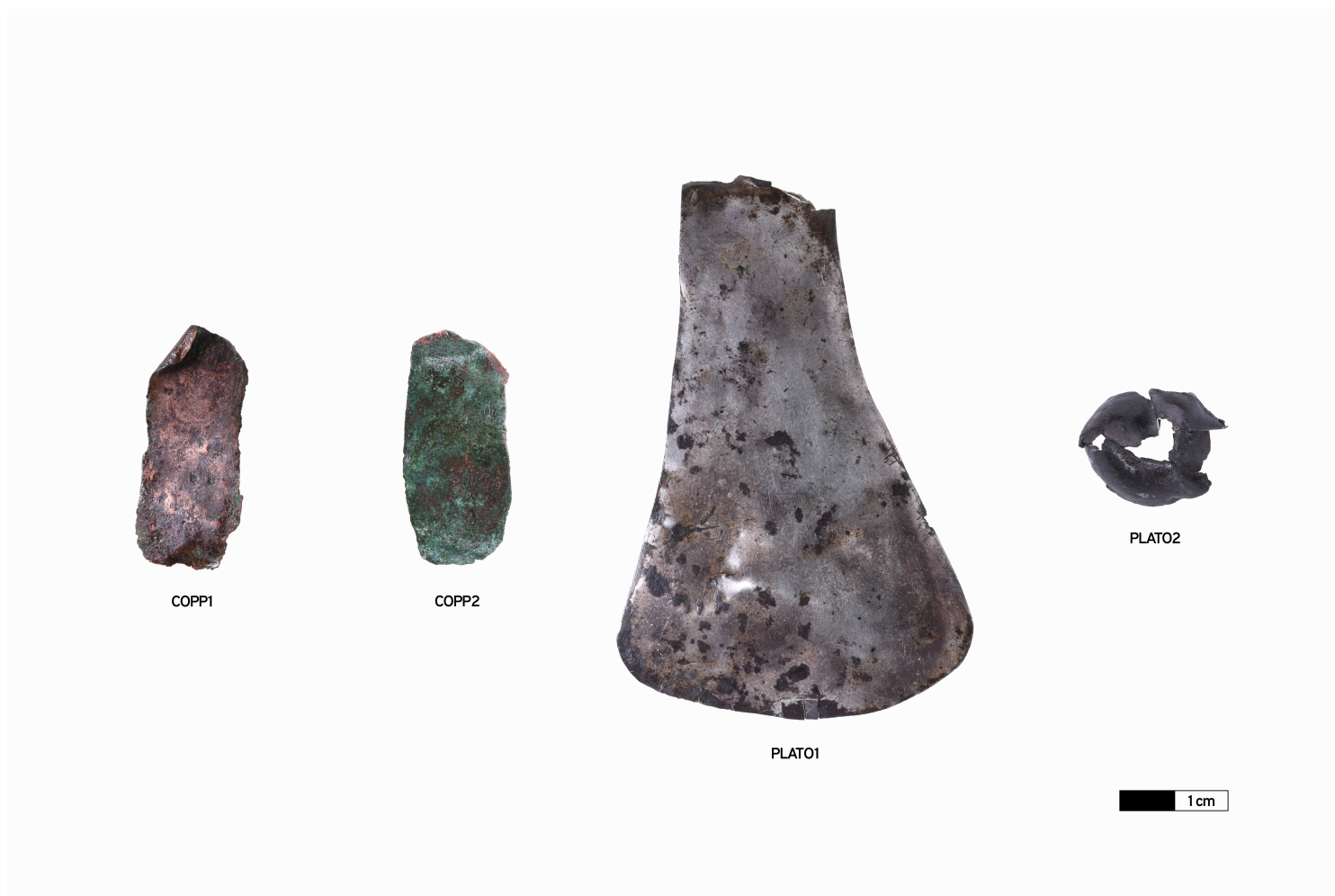


Figure 4

Photos of metal samples from the Siete Ventanas de Cochapetí tomb.

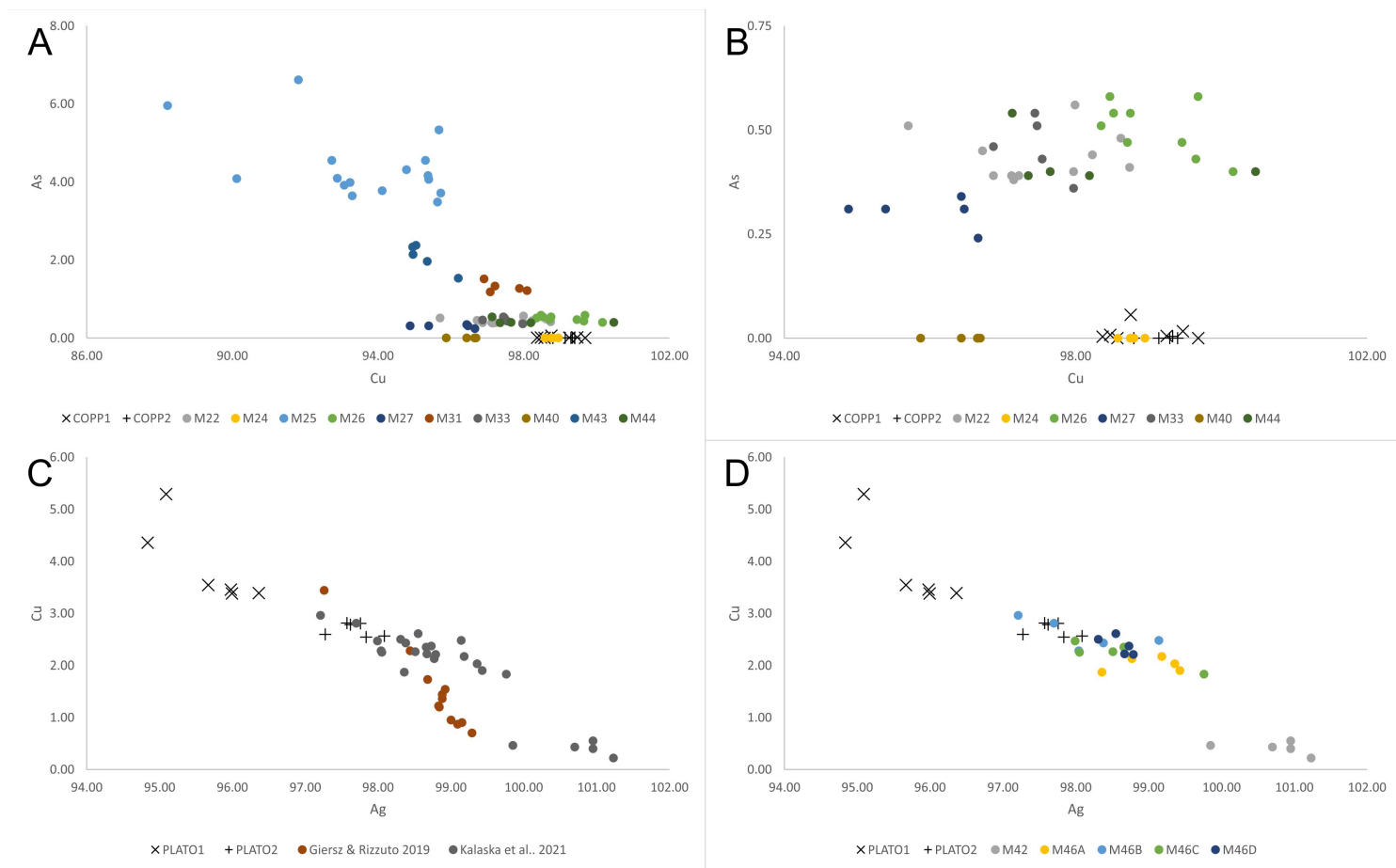


Figure 5

Comparison of the chemical composition of the main elements of the tested samples with metal samples from Castillo de Huarmey [38, 39]. A – comparison of copper samples; B – comparison of silver samples.

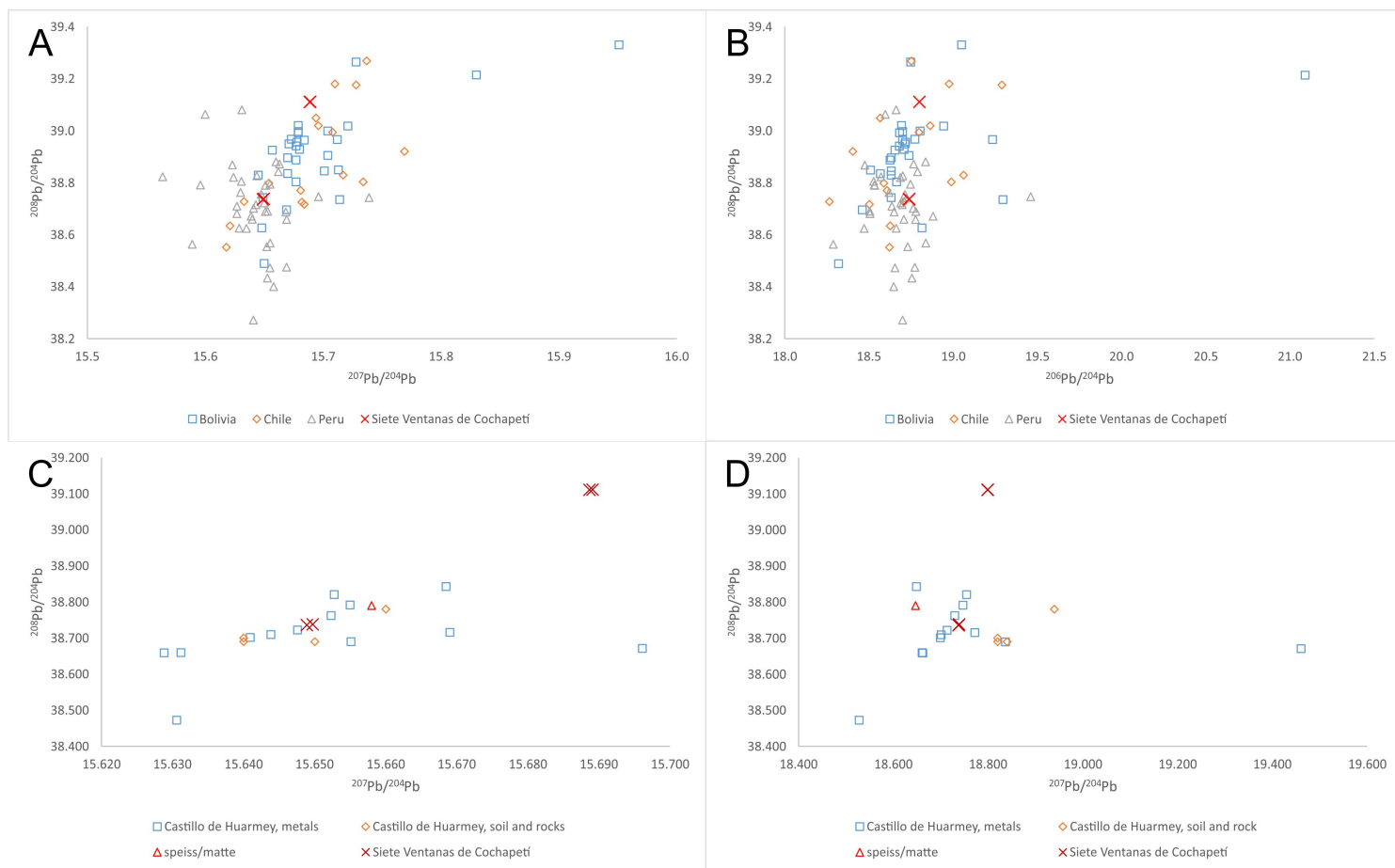


Figure 6

Comparison of Pb isotope results of the tested samples with literature data for other artefacts from Bolivia, Chile and Bolivia [27, 30, 36, 37, 40].

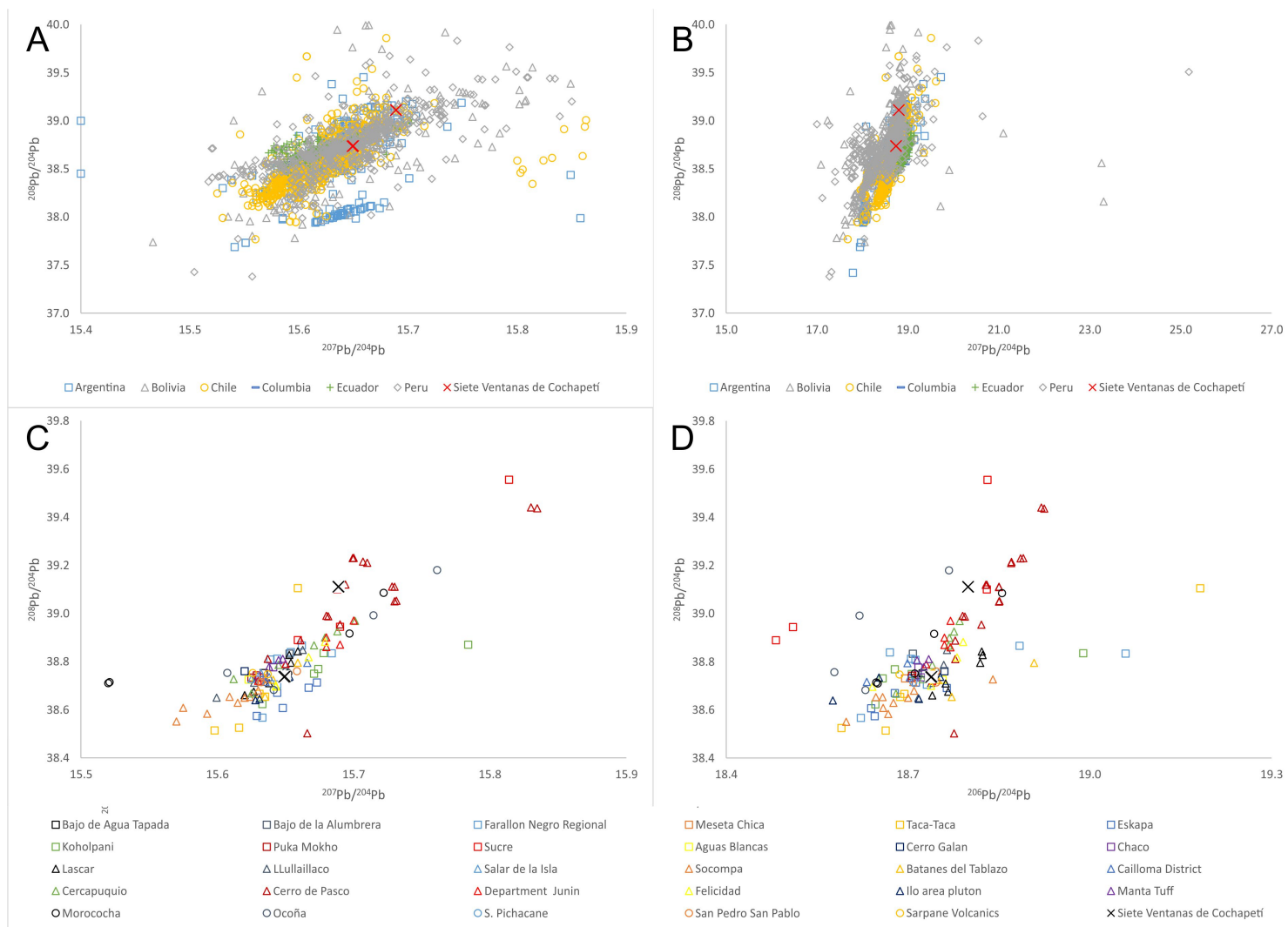


Figure 7

Comparison of Pb isotope results of the tested samples with literature data for deposits and rocks from the Central Andes area [27, 30, 36, 37, 40, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 94, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134].

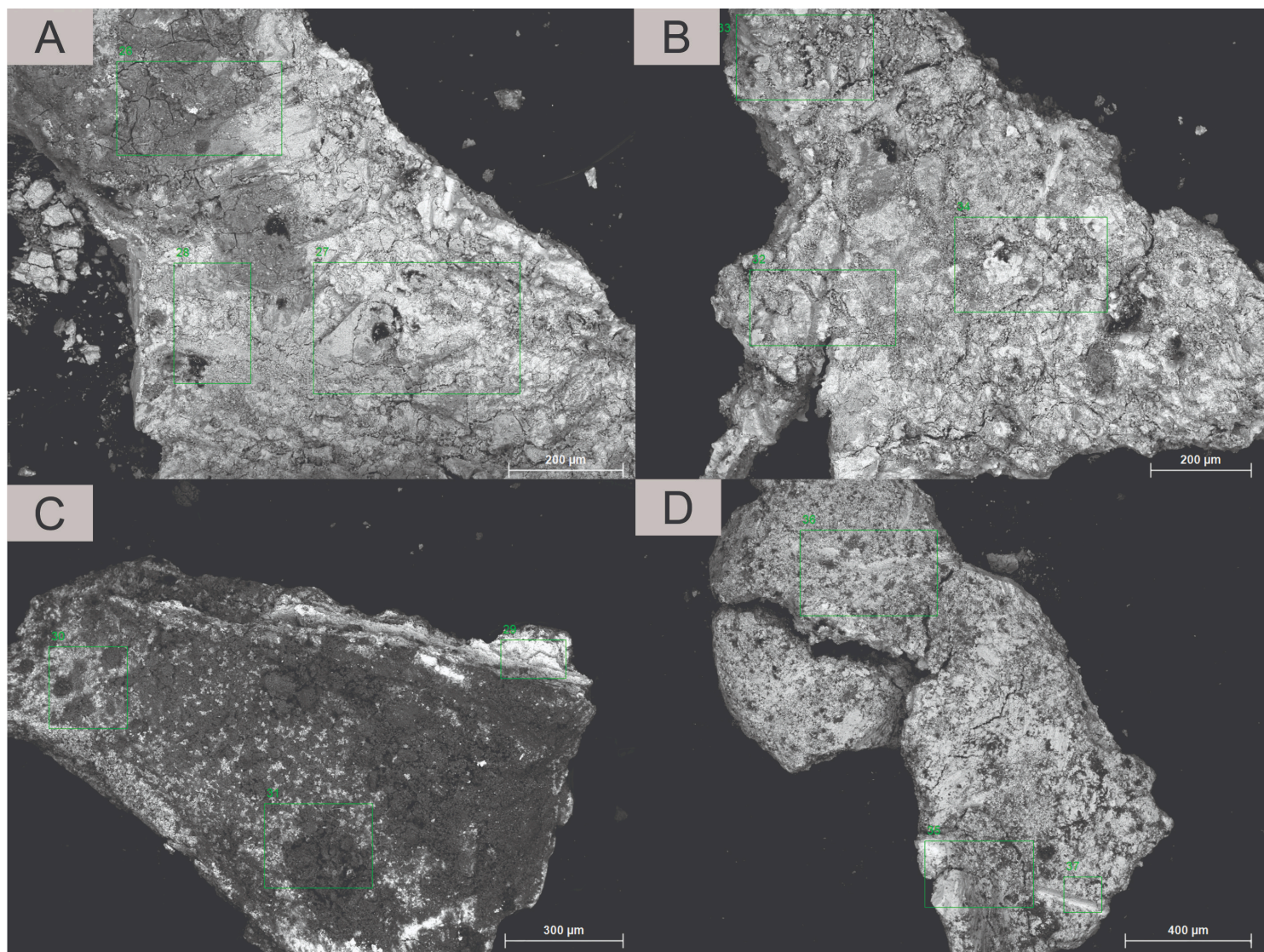


Figure 8

SEM-BSE images of the surface of metal samples: A – PRIACH_M-3; B – PRIACH_M-4; C – PRIACH_M-1; D – PRIACH_M-2.

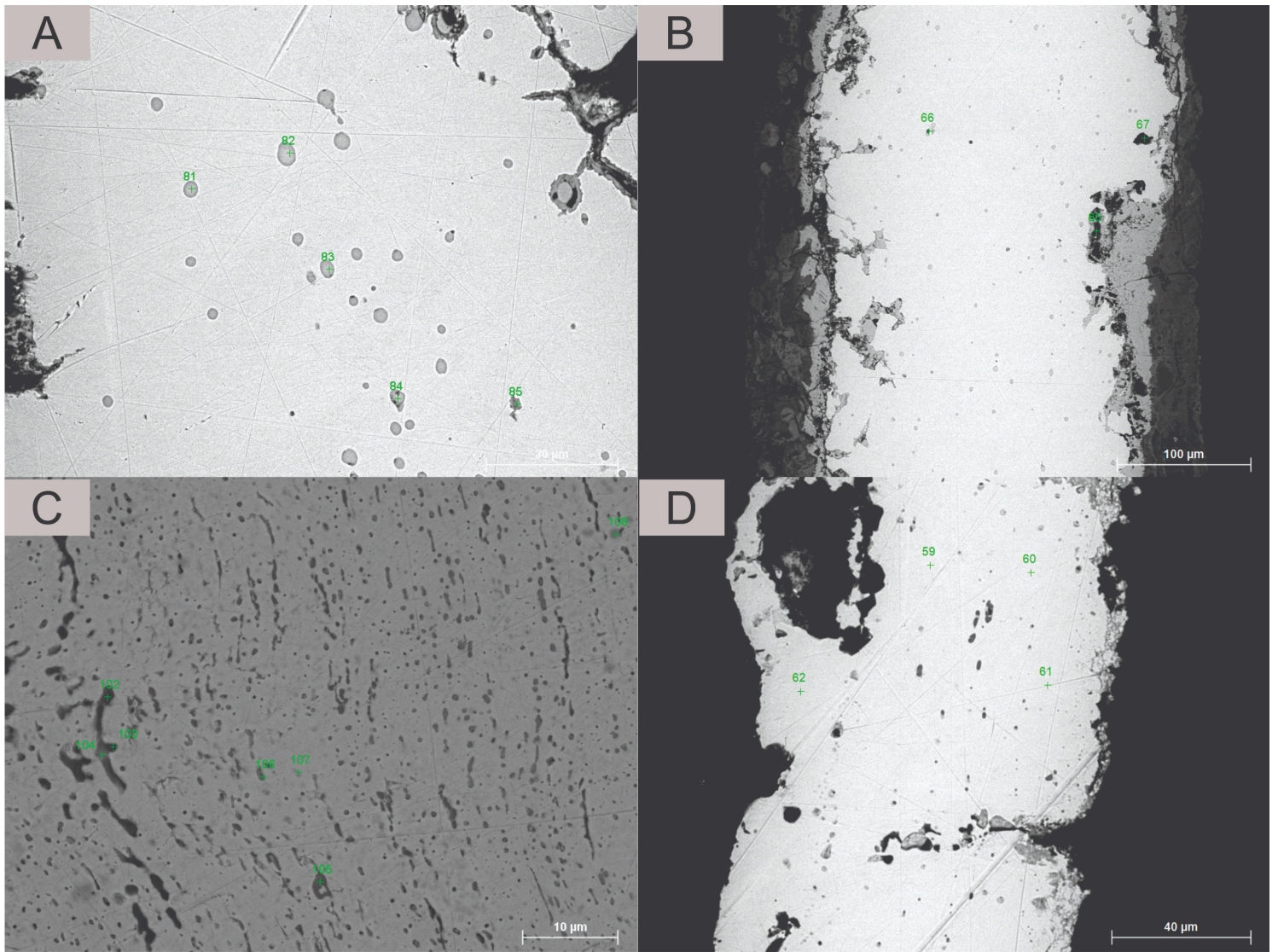


Figure 9

SEM-BSE images of cross-sections (1-inch specimen) of metal samples: A – PRIACH_M-3; B – PRIACH_M-4; C – PRIACH_M-1; D – PRIACH_M-2.

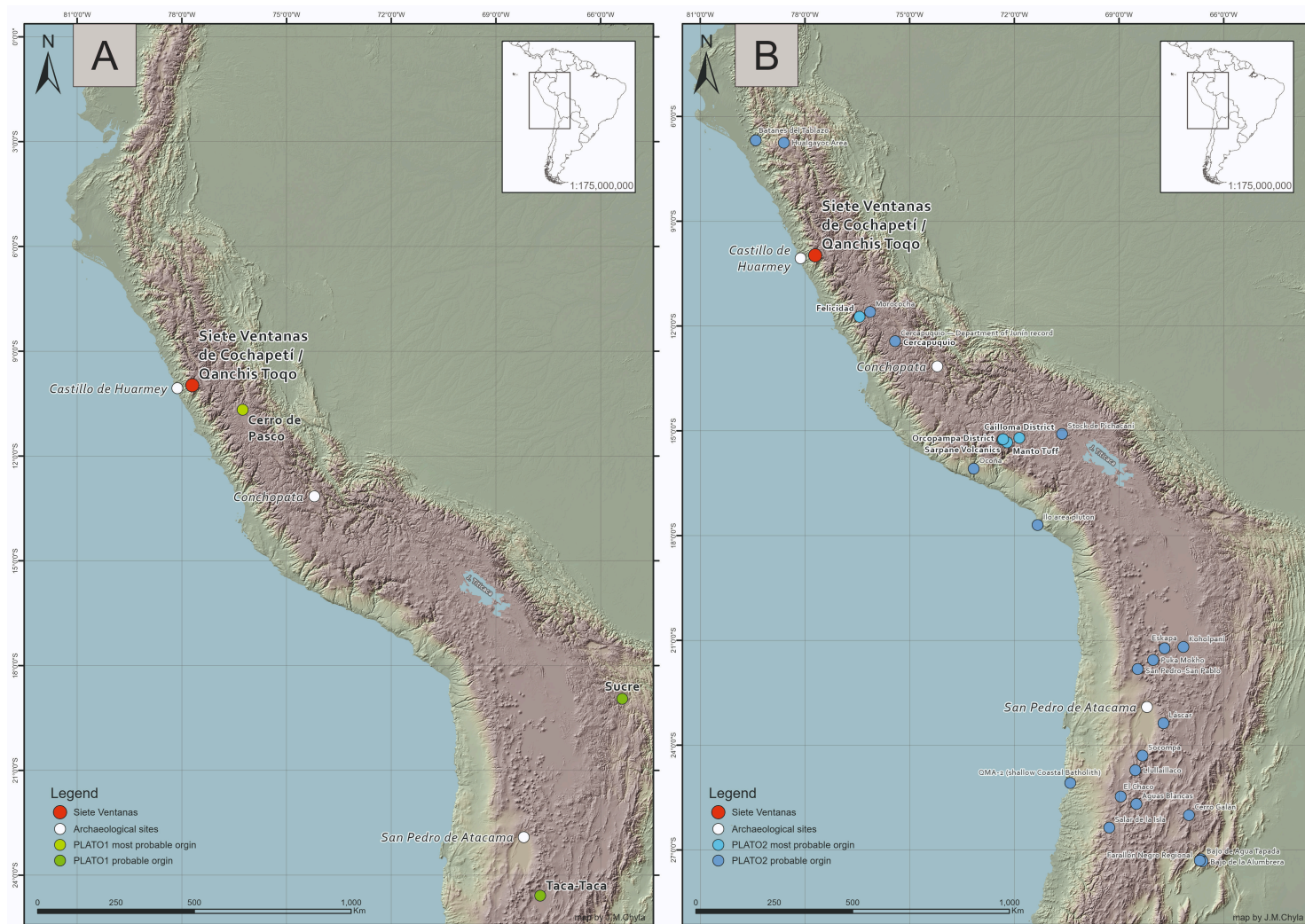


Figure 10

Map of matches of individual samples to the most probable ore sources.

Supplementary Files

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- [Supplementarymaterials1.xlsx](#)
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- [Supplementarymaterials4.docx](#)
- [Table1.docx](#)
- [Table2.docx](#)
- [Table3.docx](#)