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Beaker and Early Bronze Age Tin Exploitation in Cornwall: Cassiterite Processing Identified through Microwear and pXRF Analyses

CHRIS CAREY[1], CHRISTINA TSORAKI[2], ANDY M. JONES[3], OLIVER J.T. HARRIS[2], RACHEL J. CRELLIN[2] AND PETER LYONS[1]

[1] *School of Applied Sciences, University of Brighton, UK*

[2] *School of Archaeology and Ancient History, University of Leicester, UK*

[3] *Cornwall Archaeological Unit, Truro, UK*

The appearance of Beaker pottery in Britain and Ireland during the twenty-fifth century BC *marks a significant archaeological horizon, being synchronous with the first metal artefacts. The adoption of arsenical copper, mostly from Ireland, was followed by that of tin-bronze around 2200* BC*. However, whilst the copper mine of Ross Island in Ireland is securely dated to the Early Bronze Age, and further such mines in the UK have been dated to the Early and Middle Bronze Age, the evidence for the exploitation of tin ores, the other key ingredient to make bronze, has remained circumstantial. This article contains the detailed analyses of seven stone artefacts from securely dated contexts, using a combination of surface pXRF and microwear analysis. The results provide strong evidence that the tools were used in cassiterite processing. The combined analysis of these artefacts documents in detail the exploitation of Cornish tin during this early phase of metal use in Britain and Ireland.*

Keywords: Beaker, Cornwall, cassiterite, microwear, metallurgy, ore processing

INTRODUCTION

The arrival of Beaker material culture into Britain and Ireland during the twenty-fifth century BC is a significant moment, coinciding with the appearance of the first metal artefacts from around 2450 cal BC (Allen et al., 2012). The first metal implements in Britain were made of copper, later followed by tin-bronzes around 2200–2100 cal BC. Whilst some of these objects were placed in graves, for example with the Amesbury Archer (Fitzpatrick, 2011) or with the Racton burial in West Sussex (Needham et al., 2017), the majority of the period's metalwork, in the form of axes, was deposited as single finds or in small hoards (Needham, 2017). Early copper alloys within Britain and Ireland were largely derived from arsenical copper ore mined from Ross Island in south-western Ireland (O'Brien, 2004), which was the source of most of the copper in Britain from *c.* 2400 cal BC (Bray, 2012). Although copper mines dating to the Early Bronze Age (EBA hereafter) have been discovered in recent decades, such as Copa Hill, Cwmystwyth, in Wales, Ecton Hill and Alderley Edge in the English Peak District (Timberlake, 2003, 2014, 2017; Timberlake & Pragg, 2005), and the largely Middle Bronze Age mine at Great Orme in Wales (Williams & Le Carlier de Veslud, 2019), Ross Island is currently the earliest mining site known in Britain and Ireland (Carey et al., 2019), although some of the earliest deposits at Copa Hill could date to a similar period (Timberlake & Craddock, 2013).

Bronze is an alloy of copper and tin; though it has been postulated that tin was obtained from the rich metalliferous deposits of south-western England (Budd & Gale, 1997; Haustein et al., 2010), the evidence for its exploitation in the Bronze Age remains largely elusive. The numerous Middle Bronze Age artefacts recovered from tin streamworks in Cornwall provide evidence for prehistoric exploitation (Penhallurick, 1986: 173–224), and this has recently been confirmed by a date of 1620–1497 cal BC (3269±27 BP, OxA-36336 at 93.9% confidence) obtained for an antler pick from the Carnon valley near Truro (Timberlake & Hartgroves, 2018). Furthermore, two EBA pits recently excavated in Cornwall contained several kilos of cassiterite pebbles, granules, and ore, demonstrating the collection of alluvial cassiterite for processing (see below Truro TEDC; Taylor, 2022).

Evidence for EBA metalworking in the south-western English peninsula, such as furnaces or 'smithies', has not been identified and potential data are again restricted to indirect clues including stone moulds and hammerstones (Craddock & Craddock, 1997; Timberlake & Craddock, 2013; Brügmann et al., 2017). Significantly, fragments of tin slag were recovered from an EBA barrow at Caerloggas in Cornwall (Miles, 1975); however, smelting took place off-site, the slag having been deposited in a secondary context. Currently, the earliest *in situ* evidence for metalworking in southern Britain dates to the Middle Bronze Age, at Tremough (Cornwall), where moulds and a hearth indicate that bronze was cast inside a roundhouse dated to *c.* 1500–1300 cal BC (Jones et al., 2015; Webley et al., 2020: 84).

This sparse evidence for the exploitation of metalliferous resources in south-western Britain and indeed western Europe (Gandois et al., 2020) during the EBA presents a paradox, as the Cornish peninsula is rich in copper, gold, and especially tin (Penhallurick, 1986; Timberlake, 2017; Radivojević et al., 2018). Recent advances in analytical techniques, including isotopic analysis of artefacts and identification of potential ore sources, have revealed that traces of these metals from south-western England were probably present in Bronze Age artefacts (Rohl & Needham, 1998; Haustein et al., 2010; Bray & Pollard, 2012).

Cornish gold may have been circulated before *c.* 2000 cal BC to make lunulae, which are found in Ireland and Atlantic Europe (Standish et al., 2015), and gold from the river Carnon, along with tin from the Redruth area, may have been used in the Nebra Sky Disc (Esher et al., 2011; Borg & Pernicka, 2017). We have good reason, and increasingly good secondary evidence, to believe that sources of tin and gold in south-western Britain were being exploited, but no direct indications of how or where this was happening. Understanding metalworking in this region has implications for our knowledge of this period across north-western Europe: evidence for tin exploitation is a critical missing piece of the puzzle.

Newly Discovered Sites in Cornwall

It is within the context of a lack of evidence of EBA exploitation of metalliferous resources within south-western Britain that three excavated sites in Cornwall are significant: two, Sennen and Lelant, are associated with Beaker pottery, and a third, in Truro, dates to the EBA (Figure 1). These have the capacity, as we will demonstrate, to provide new evidence for tin ore extraction and processing, increasing our understanding of the development of these traditions in Britain and their role further afield. Here we describe the new sites before outlining the analytical tools employed to document the exploitation of tin (for site descriptions contexts given as (XXX) are a deposit or fill, with contexts given as [XXX] being a cut feature).

Sennen PS07: Structure 108

The excavation of an EBA site at Sennen identified Structure 108, an irregular oval feature measuring 4.2 × 3 m aligned on a north-east to south-west axis (Jones et al., 2012; Figure 2). The interior was deliberately sunken (by 0.25 m) and around the perimeter were at least eight small postholes, potentially supporting a superstructure. An area of burning indicated a possible internal hearth (103), 1.1 × 0.85 m, located in a slight hollow in the floor in the structure's south-western half. A single, deliberate, backfill (89) sealed the structure and contained many artefacts, including Beaker pottery, twenty one flints comprising six waste pieces, one split pebble and 14 tools including an engraver, which was probably hafted, and thirteen stone tools (including SF2, SF3, and SF5, discussed below), dated to 2337–2059 cal BC (SUERC-21077, 3785±30 BP, 95%).

A row of postholes was found outside the north-western side of Structure 108, on the same north-east–south-west alignment, and to the north-east and east of Structure 108 there was an alignment of pits and postholes set at right angles to the posthole row. Several pits were also identified, some of which contained flint, Beaker pottery, and worked stones. To the immediate east was a complex of features which included a hearth [105], the upper fill of which (128) contained a greenstone pestle or pounder (SF33); this fill yielded a date of 2451–2146 cal BC (SUERC-21075, 3825±30 BP, 95%). Radiocarbon determinations from Structure 108 and the surrounding features demonstrate occupation between *c.* 2300 and 2100 cal BC, and the nature of the architecture indicates that the occupation was short-lived (see Jones et al., 2012 for a full description). The slight character of Structure 108 is consistent with other contemporary 'buildings' associated with Beaker material (Darvill, 1996; Gibson, 2019; O'Brien, 2004; Sharples 2009).

Lelant TR18: Pit [6]

Archaeological monitoring at Lelant on the western side of the Hayle Estuary revealed a single pit associated with Beaker pottery, worked stone, and four flint artefacts, which included an end scraper and multi-purpose knife (Jones & Lawson-Jones, forthcoming) (Figure 3a). Pit [6] had a diameter of 0.7m, was 0.16m deep, and was buried beneath aeolian (dune) sands. The pit contained a single deposit, with clustered sherds of Beaker pottery from a single vessel, which, given their poor condition, are likely to derive from a curated vessel. The flint and worked stone artefacts were arranged around the base of the pit. Three of the four flint tools were found together, and two are likely to have come from the same core. The worked stone assemblage comprised three items. The first, is a flat beach cobble, which may have been selected for deposition, as distinctive-looking pebbles and stones are often found within ritualized contexts during the Bronze Age (Tilley, 2017). The third object, a greenstone grinder or pounder (S1), is also highly distinctive.

The arrangement of the artefacts in pit [6] indicates more than the routine discard of occupation material. The assemblage represents both a deliberate clustering and a separation of different types of artefacts into distinct groups. There was deliberation in the choice of stone-processing tools which were selected and sourced from different geologies and used for separate tasks. The deposit thus contains a set of visually distinctive tools, which are likely to have been associated with particular people, activities, and places. The pit's location close to the Hayle Estuary may be significant as this was an important waterway linking people and places in the Bronze Age (Brück, 2019: 220–23; Johnston, 2020: 140–45).

Truro TEDC: Pit [3417]

The TEDC site on the eastern side of Truro comprised numerous pit groups spanning the Neolithic and EBA, many of which had been deliberately infilled (Taylor, 2022). Two of these pits, securely dated to the EBA, contained cassiterite (Figure 3b and 3c). The bowl-shaped pit [3417], 0.5 m in diameter and 0.24 m deep, was found in isolation and contained two fills. The lower, dated to 2010–1964 cal BC (SUERC-64604, 3543±30 BP, 95%), contained cassiterite-rich cobbles weighing *c.* 1.25 kg and the environmental sampling residue contained a further 9.1 kg of crushed cassiterite. The upper fill contained 2.6 kg of cassiterite ore and pebbles, and the top of the pit was sealed by a large grinding tool (S29). The deposition of a significant quantity of crushed cassiterite, which was a valued material, coupled with the placing of the grinding tool across the top of the pit strongly suggests that it was a structured deposit. A second pit [2447] was also associated with cassiterite and abraded Collared Urn sherds; five waste flints and small rounded cassiterite granules were found at its base. The upper fill contained a large quantity of Trevisker pottery (a style particular to EBA south-western Britain), flints and nearly 0.6 kg of cassiterite pebbles. Two radiocarbon determinations were obtained from the lower and upper fills, respectively: 2027–1774 cal BC (SUERC-64448, 3567± 7 BP, 95%) and 1870–1622 cal BC (SUERC-64580-3414±28 BP, 95%). The dates for [2447] straddle a long timeframe, allowing for the possibility that infilling was slow, although the pit was shallow and there was no sign of silting between the layers. The abraded Collared Urn sherds in the primary fill also contrast with the Trevisker sherds in the upper fill. This suggests that the pit received two distinct artefact-rich caches in succession.

MATERIALS AND METHODS

Sequence of analysis

Initially, the stone tool assemblages from Sennen (PS07, fifteen artefacts), plus selected artefacts from Lelant (TR18, one artefact), and Truro (TEDC, one artefact) were analysed by portable X-Ray Fluorescence (pXRF hereafter) scanning to detect elements associated with metalliferous ores. When elements such as tin (Sn) were detected, the stone tools were subjected to a more detailed pXRF analysis. This used an Innov-X Alpha Series instrument, using a 5-minute count time per reading, obtaining indicative readings for Al, Si, P, K, Ti, V, Cr, Mn, Fe, Ni Cu, Zn, As, Rb, Sr, Sn, W, Zr, and Pb. Given the calibration limitations of the pXRF technique, a bespoke set of Sn calibration standards were used to quantify the Sn data values. Principal Component Analysis (PCA) was used to define geochemical signatures within the data. A selection of artefacts were subsequently subjected to microwear analysis, including those that displayed elevated levels of Sn, as well as some artefacts chosen for their morphological and technological features (e.g. SF2).

Microwear analysis is a technique that identifies microscopic wear traces that develop on the surface of objects during manufacture, use, handling, but also post-depositionally (van Gijn, 2010, 2014). Microscopic observations were conducted at low (<100×) and high magnifications (100× and 200×) utilising a stereomicroscope (Leica M80) with an external, oblique light source and a coaxial illumination unit (Leica M80 LED5000 CXI; magnifications up to 230×), and an incident light (metallographic) microscope (Leica DM1750M) with a Leica MC120 HD digital camera. Previous functional studies of stone tools used in mining activities in Britain have focused on macroscopic inspection (e.g. Gale, 1995; Jenkins 2021), and other examinations of metalworking tools have used somewhat different techniques (e.g. Cowell and Middleton 2011). This article presents the first application of an integrated approach that combines high-resolution microwear and pXRF analyses of stone metalworking assemblages in Britain and Ireland. For further details of the methods used and the artefacts analysed, see the online Supplementary Material.

RESULTS

Microwear traces and tin concentrations

To establish the use of the selected tools, we combine the results from the two techniques in a cautious approach that looks for agreement between competing lines of evidence. Table 1 summarizes the tools that show evidence of use against a hard mineral material (see also Figure 4). Table 2 combines evidence from the pXRF and microwear analyses to interpret tool use and its relationship with metal production.

The analysis of the complete pXRF dataset revealed a clear geochemical signature related to cassiterite tin ore (Sn, Pb, As, and W) (Wang et al., 2016), defined by Principal Components 4 and 5. The pXRF data detected the presence of some high, but also variable, tin levels on the artefact surfaces, which are interpreted as partly derived from surface residues (based on higher levels on working surfaces) and partly from the artefacts' natural lithologies. The microwear analysis defined a restricted range of actions, namely crushing and grinding, traces of which were found occasionally on the same surfaces. The microscopic wear traces suggest the processing of a semi-hard material of mineral origin; based on observed wear traces, including micropolish features, and on experimental data (e.g. Hayes et al., 2018), we can exclude the possibility that these traces derived from the processing of materials such as plants or grains, bone, wood, or clay. In places the observed wear traces include a micropolish of highly reflective appearance and in this case mineral micro-residues were incorporated within the micropolish during its formation (Figure 5). This agrees with previous findings that proposed that the presence of copper micro-residues within micropolishes on stone tools was due to metallurgical activities (Hamon et al., 2020: 12–13).

Given that neither technique provides data that unequivocally defines tin ore processing, several lines of reasoning can be used to support our interpretation. The Cornish Gramscatho sandstone of the large grinding tool (TEDC S29) found with the cassiterite ore acts as a comparator for the other stone tools; it has some very high tin levels recorded, but it also has some tin elevations that are directly comparable to some readings on the other tools. Likewise, microwear on TEDC S29 includes traces (e.g. reflective micropolish, grain removal) that are consistently observed on the other stone tools. Moreover, the micropolish and other wear patterns identifiable on the stone tools are consistent with mineral processing. There is a close association between higher tin elevations and tool surfaces with developed micropolishes; this strongly suggests that some of the Sn readings relate to the function of the tools. Finally, it is possible that the tools were used on another hard mineral material that was not cassiterite, e.g. haematite (for use as a dye) or chalcopyrite (copper ore); there are, however, no distinctive staining or pigment particles on the artefacts (see Hayes et al., 2018) to support this, or any corroborating geochemical evidence. For each stone tool, we therefore indicate how confident we are that the stone tools were used within metalworking (Table 2).

DISCUSSION

The stone tools

The microwear patterns and residues observed indicate that the tools were used to process a semi-hard mineral material. The pXRF analysis detected the presence of tin, associated with lower values of arsenic and tungsten, on six implements. Both arsenic and tungsten have been recorded as trace impurities within Cornish cassiterite ore and tailings (Yim, 1981; Camm et al., 2004), in prehistoric and historic Cornish tin slags (Tylecote et al,. 2010), and within the probable Bronze Age tin ingots from the Salcombe shipwreck in Devon (Wang et al., 2016). The presence of this elemental grouping indicates that cassiterite ore is the signature's source. The stone tools analysed are made from granite, greenstone, quartzite, or sandstone and define a sub-group of artefacts that are geochemically different (due to elevated Sn levels) from the other predominantly local beach cobbles (although TEDC S29 is sandstone cobble probably collected from a river bed) characterizing the sites' wider stone assemblages. Significant variations in the relative tin concentrations between artefacts and across the surfaces of individual tools are interpreted in terms of tool function, lithology (especially for the granitic stone tools), and post-recovery artefact cleaning procedures with water, which is likely to have removed or reduced some tools' residues. Our interpretation has prioritized the information gained from microwear analysis where the pXRF data are weaker. This is because we have a better understanding of the effects of post-depositional processes on microwear traces (see Marreiros et al., 2015; Hayes et al., 2018) than we have on the presence of residues detectable through pXRF analysis.

All tools survive complete, and they retain the cobbles' original morphology. The tools show consistency in raw material use, with an emphasis on cohesive and dense materials that could effectively withstand impact. This is also suggested by the consistency in the percussive tools' size and weight (see Table 1). The microwear analysis indicates that they were used for crushing, grinding, and pounding. The cobbles were modified, mainly through use, and they exhibit moderate degrees of wear (see Adams, 2014). The creation of hafting hollows or finger grips ('comfort features': Adams, 2014: 103) on SF2, SF3, and SF5 allowed for easier handling, suggesting that intensive use was intended. This is supported by the employment of multiple surfaces on each tool, possibly indicating an attempt to maximize the potential of each implement. However, with the exception of SF33, none of the recorded implements were used for an extensive period.

The weight of the five Beaker tools (SF2, SF3, SF5, SF18, and TR18 S1) ranges from 500 to 743 g. Percussive traces on SF2, the heaviest implement (743 g), are consistent with its use for breaking up larger nodules. This tool could be associated with an early phase of a multi-stage ore processing sequence (see O'Brien, 2015: 224). In this case, the addition of a haft would have increased the tool's downward impact force. Following this stage, grinding or pounding tools weighing less than 700 g (e.g. SF3, SF5, and SF18) were used for crushing and pulverizing the larger fragments into finer particles to produce a fine concentrate for smelting (O'Brien, 2015: 225). Likewise, Lelant S1 was used for crushing and fine grinding of mineral material, and its intentionally polished surface may have also been used for the smoothing and shaping of metal, thereby providing associations with the final stages of metal production. Tools weighing between 100g and 500g (SF33 and SF5) were also potentially used for crushing and pulverizing; in the case of SF33 this may have involved a rotational motion executed in a basin or hollowed surface. Based on their weight and the macro- and microwear traces, the Cornish tools are consistent with processing smaller ore fragments rather than direct mining. Cassiterite pebbles eroded out of tin lodes would have been easily visible and collectable from the gravel bedload in Cornish streams and rivers. The exception is S29 from TEDC18. This tool's lithology differs from that of the other tools and it was used differently as a stable lower grinding surface. At Copa Hill, one larger anvil stone was located amongst generally smaller hammerstones (Timberlake & Craddock, 2013) and thus the size of S29 might relate to its function in processing alluvial tin. However, EBA stone assemblages, as opposed to those associated with Beaker material, tend to be more diverse (Watts, 2014: 98-101). The larger size of S29 could thus be related to functional aspects of tool use (as a lower grinding tool), reflect changing styles of artefacts morphologies and/or structured deposition in the EBA.

The tools in their wider context

An important aspect of the stone tool assemblages from Sennen and Lelant are their early date. Needham et al. (2017) estimate the earliest tin bronzes to be in circulation within Britain around 2200–2100 cal BC. Given the relatively quick adoption of bronze at this time (in comparison to continental Europe where copper has a more extensive history), the evidence of processing cassiterite ore in Cornwall between 2300 and 2100 cal BC is highly significant.

Research on copper sources, both in terms of their excavation (e.g. Dutton & Fasham, 1994; O'Brien, 1994, 2004, 2013, 2015; Timberlake, 2003, 2014, 2017; Timberlake et al., 2004; Timberlake & Pragg, 2005) and the understanding of their chemical signatures (Ixer & Budd, 1998; Rohl & Needham, 1998; Bray & Pollard, 2012), has been very successful over the last three decades. Yet the discovery of tin mining and processing remains elusive. Copper-containing deposits, such as malachite, azurite, fahlore, bornite, and chalcopyrite, were exploited in Bronze Age Europe generally by open-cast techniques alongside surface pits, surficial deposit exploitation, and underground workings (O'Brien, 2013: 447; 2015). These sources were mined with relatively simple lithic technologies often in combination with wooden and bone tools (though at Great Orme, between 1600 and1400 cal BC, bronze tools were potentially used in the mining process: Williams & Le Carlier de Veslud, 2019: 1181). Firesetting was commonly used to break up rock surfaces allowing lithic tools, likely hafted, to be swung underarm to break up the surface and extract the ore (Timberlake & Craddock, 2013). These technologies and techniques reflect the nature of the copper deposits exploited at this time in Europe, where solid mineral deposits were being extracted from bedrock lithologies. Tin (and gold) are quite different, in that they often occur as eroded fragments in secondary deposits, such as alluvial gravels and other surficial deposits; therefore, they do not require the same extractive techniques. Timberlake (2017: 719, 722) has argued that prospection for early gold from alluvial sources may have been linked to the discovery of tin in those same environments thus strengthening our perception of the connection between Ireland and south-western England and suggesting a movement back and forth of gold, tin, and copper. He also noted the lack of evidence for the exploitation of the rich copper deposits of south-western England, suggesting that the exploitation of the two metals may have been mutually exclusive (Timberlake, 2017: 723), at least during the EBA (2450-1600 cal BC).

Many mining sites have been identified as belonging to the Bronze Age on the basis of the hammerstones recovered there. As Timberlake and Craddock (2013: 39) discuss, a wide range of terms are employed for these tools, including stone mining mauls, stone hammers, hammerstones, pounders, crushers, stone picks, and stone anvils; they prefer to use the term 'cobble stone mining tool' because this captures their variability and interchangeable uses. The Ross Island lithic assemblage (containing over 7000 hammerstones) includes percussive tools, derived from well-rounded alluvial waterworn cobbles selected for their rounded shape (often elliptical, oval, or pear shaped) and lithology. The weight of the percussive tools used for processing ore was a significant variable, with a preference for cobbles weighing between 500 and 1500 g for hammerstones, and lighter cobbles (100–500 g) used as specialized pecking tools; these cobbles were brought to Ross Island specifically for mining and processing ores and 86 per cent have some kind of modification to allow hafting (O'Brien, 2004: 341–47). The assemblage is comparable to the slightly later material from Mount Gabriel (O'Brien, 2004: 339), though only 47 per cent of the Mount Gabriel hammerstones show signs of hafting (O'Brien, 2004: 347); they are thought to have had a shorter use life.

The analysis of the cobble stone mining tools from Copa Hill revealed that at least 79 per cent were smoothed and rounded, suggesting they came from beaches or rivers; the majority weighed around 2–2.25 kg and were around 15–25 cm long and 8–13 cm wide (Timberlake & Craddock, 2013: 42). Timberlake and Craddock (2013: 42) argue that the cobbles were selected not only for their texture and size but also for their shape, with a clear preference for cylindrical or flat-sided exemplars. They note that there is a slight preference for finer-grained and harder rocks, which may indicate that form and size were generally more important than geology. The probable source of the cobbles used at Copa Hill was at the storm beach shingle bars near the mouth of the river Ystwyth some 25k m away (Timberlake & Craddock, 2013: 42).

There are some key overlaps and differences between the stone tools from these mining sites and the stone tools associated with tin processing presented here. The stone tools we analysed are well-worn and rounded cobbles that appear to have been selected for their shape and their cohesive dense lithology suitable for heavy work. The assemblage discussed here is lighter in weight and smaller in size than the tools from Ross Island, Mount Gabriel, and Copa Hill but this is not unexpected; the latter were used to extract mineral ore associated with solid bedrock, whilst the tools from our sites were primarily used at a later stage in the *chaîne opératoire*, processing alluvial cassiterite that was already broken down into smaller particles through natural fluvial weathering. There is also an overlap with some of the grinding slabs and anvil stones identified at the settlement site associated with Ross Island (O'Brien, 2004: 356–59) and S29 from TEDC, which was also used as a grinding slab. These Ross Island tools are associated with the processing (rather than mining) of copper ore, being used as a surface for grinding and crushing, and the same processes are suggested for S29, albeit for alluvial tin (Figure 6).

The tools analysed here are not those used for extraction and mining but are those used in processing. In terms of the structures they are associated with, there are also some similarities and differences between Ross Island (particularly Structure C) and Sennen's Structure 108. They are of similar size and shape, although the Ross Island structures were defined by gullies and several of the structures are much larger, whilst Sennen Structure 108 was sunken. There is also more evidence for intensive activity, centred around a mine, on the Ross Island site and its chronological span is longer (*c*. 500 years, but see Carlin, 2018 who questions their association with the site's active period of mining). The site at Sennen is interpreted as shorter lived and more likely to have been associated with the collection of readily available cassiterite from streams, which may have contributed to its temporary nature.

Finding Bronze Age tin

The absence of evidence for tin mining and processing has long been a puzzle in Bronze Age Britain and Europe. At Sennen, the stone tools interpreted as having been associated with cassiterite processing were not randomly scattered across the site; all were found close to areas of burning or in features with other burnt material. Four tools (SF2, SF3, SF5, and SF18) were found above the burnt area within the infill of Structure 108, whilst SF33 was found in the hearth complex outside the structure. The association with fire is suggestive and it is possible that these hearths were used to smelt tin. Such smelting would not require a specialized furnace lining; tin can be smelted in a small ceramic vessel in a hearth with a directed air supply (Ottaway & Roberts, 2009). The excavation at Sennen yielded no moulds or crucibles, which is in line with much of the evidence for metalworking in Britain and Ireland in this period (see Webley et al., 2020). Instead we have an assemblage of stone artefacts more closely associated with processing, involving the primary pulverizing and crushing of cassiterite pebbles and subsequent grinding to produce a fine concentrate for smelting. Structure C at Sennen, whilst it has a definable relationship to cassiterite processing, is not definably a metal workshop; rather it is a slight, seasonal or temporary structure associated with a range of activities (e.g. SF14 was associated with plant processing identified from microwear analysis), similar to the situation described by Hamon et al. (2020) in Brittany. All three of our sites had evidence of the deliberate deposition of materials and objects. In certain respects, this is comparable with practices of the later Bronze Age (Webley et al., 2020: 184–86), when moulds and crucibles, as well as objects, were increasingly deposited in formal deposits.

Our analysis suggests that the search for evidence for tin exploitation is unlikely to be resolved by following traditional assumptions of what metalworking sites look like. We have, in effect, been looking for the wrong things. Instead, the primary evidence may lie in the close examination, through geochemical but especially microwear analysis, of stone tools. Stone tools in the Bronze Age are often paid less attention than lithics from earlier periods. Our evidence for the extraction of tin differs from that for the extraction of copper. In the case of copper exploitation, which targeted bedrock concentrations, it has long been stone tools that have led us to mining sites. In the case of tin, alluvial and surficial deposits of cassiterite do not require mining, but they do require similar processing, potentially undertaken with a similar toolkit of multifunctional cobbles. It is in these objects, often only briefly summarized or ignored, that the detailed evidence of how early metals were worked may lie. In the case of the tools analysed here, their deposition suggests their critical importance for people at the time, but it is in attending to the microhistories of their wear and the tiny traces lodged in their chemical composition that their role in shaping past histories can more clearly emerge.

CONCLUSION

The small-scale collecting and smelting of tin ores, primarily from cassiterite pebbles, is unlikely to have left direct traces in the archaeological record, and hence we must apply other suites of analyses to detect such activity. The study of artefacts, using geochemistry alongside microwear analysis, can substantively contribute to understanding the processing of metal ores and the finishing of metal artefacts (see Hamon et al., 2020). Our study highlights the value of applying combined microwear and pXRF analyses to stone tools from EBA sites.

In an article summarizing the state of research concerning Bronze Age mining and metal production, Simon Timberlake (2017: 716) wrote: ‘There is good circumstantial evidence and a strong narrative tradition which asserts Cornwall (and Devon) to be the European home(s) of prehistoric tin’**.** Our results strongly suggest that Cornish tin sources were being processed from as early as *c.* 2300–2200 cal BC, and that ores from these sources were integrated into the circulation of metals, first across Britain and Ireland and subsequently in the wider Atlantic region and beyond (Berger et al., 2022). This ties in with the goldwork evidence, in terms of the Atlantic distribution of the broadly contemporary lunulae found in Ireland, Cornwall, and Brittany (Taylor, 1980; Needham, 2000), and with respect to geochemical analyses which have identified Cornish gold in other artefact types (Esher et al., 2011; Standish et al., 2015; Krause et al., 2021). We can therefore potentially see tin and gold from Cornwall, and copper from Ireland and Wales, as forming part of a wider Atlantic exchange network. The discoveries presented here constitute not only the earliest secure evidence for tin exploitation in Britain, but also they showcase a new methodological approach for identifying tin processing, opening up a critical new perspective on the emergence of bronze.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit

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Biographical Notes

Chris Carey is a Principal Lecturer at the University of Brighton. He specialises in archaeological science and geoarchaeology, researching in areas such as prehistoric landscape dynamics and change, archaeometallurgy and geospatial data modelling. Current research projects include investigating the signatures of landscape use between the Early and Middle Bronze Age, applying multi/hyperspectral remote sensing technologies to map prehistoric land divisions and modelling the alluvial sedimentation at Avebury identify landscape change and transition.
Address: *School of Applied Sciences, University of Brighton, UK. BN2 4GJ.* . [email: C.J.Carey@brighton.ac.uk]. https://orcid.org/0000-0001-7459-9640

Christina Tsoraki is an Honorary Fellow at the University of Leicester. She was previously a Postdoctoral Research Associate working on the Leverhulme-funded *Beyond the Three Age System* project. She specialises in prehistoric archaeology focusing on material culture studies, stone technology and microwear analysis. Her research interests include object histories, cross-craft interactions, depositional practices and household archaeology. Between 2012 and 2018 she was the Head of the Ground Stone team for the Çatalhöyük Research Project (Turkey). She is co-editor of *Communities at Work: the making of Çatalhöyük* with Ian Hodder.
*Address***:** School of Archaeology and Ancient History, University of Leicester, University Road, Leicester, LE1 7RH UK. [ct293@leicester.ac.uk:]. ORCiD: https://orcid.org/0000-0001-9282-0847

Andy M. Jones is the Projects Manager at Cornwall Archaeological Unit. His research interests include the Neolithic and Bronze Age of western Britain. Major publications include: *Settlement and Metalworking in the Middle Bronze Age and Beyond: New Evidence from Tremough, Cornwall* (2015), *Preserved in the Peat: an Extraordinary Bronze Age Burial on Whitehorse Hill, Dartmoor, and its Wider Context* (2016) and *Later Prehistoric Settlement in Cornwall and the Isles of Scilly: Evidence from Five Excavations* (2021).
Address: Cornwall Archaeological Unit, Pydar House, Pydar Street, Truro, UK. [email:Andy.Jones@cau.org]. ORCiD: https://orcid.org/ 0000-0001-9349-7818

Oliver J.T. Harris is Associate Professor of Archaeology at the University of Leicester. His research interests focus on the Neolithic and Bronze Age of Europe and archaeological theory, and he directs fieldwork on the Ardnamurchan Peninsula, excavating sites from all periods. He is the author of Assembling Past Worlds (Routledge), and a co-author of

Archaeological Theory in Dialogue, Archaeological Theory in the New Millennium (both Routledge) and the Body in History (CUP).
Address: School of Archaeology and Ancient History, University of Leicester, University Road, Leicester, LE1 7RH UK. [email: ojth1@leicester.ac.uk]. ORCiD: https://orcid.org/0000-0002-2053-9172

Rachel J. Crellin is Associate Professor of Archaeology at the University of Leicester. Her research interests centre on archaeological theory, Neolithic and Bronze Age Britain and Ireland and metalwork wear analysis and she directs fieldwork on Neolithic and Bronze Age sites from the Isle of Man. She is the author of Change and Archaeology (Routledge) and a co-author of Archaeological Theory in Dialogue (Routledge).
Address: School of Archaeology and Ancient History, University of Leicester, University Road, Leicester, LE1 7RH UK [email: rjc65@leicester.ac.uk]. ORCiD: https://orcid.org/0000-0002-8297-1083

Peter Lyons is technical manager for the Department of Earth and Environment at the University of Brighton. He oversees the Geochemical Laboratories, providing analytical services to research projects form across the School of Applied Sciences.
Address: *School of Applied Sciences, University of Brighton, UK. BN2 4GJ.*[email:]. P.lyons2@brighton.ac.uk ORCiD: https://orcid.org/0000-0002-8003-0845

L'exploitation de l'étain au Campaniforme et au Bronze Ancien en Cornouailles : le traitement de la cassitérite identifié par analyses des microtraces et par fluorescence des rayons X

L'introduction de la céramique campaniforme en Grande-Bretagne et en Irlande durant le vingt-cinquième siècle av. J.-C. marque un horizon archéologique important qui coïncide avec l'arrivée des premiers objets en métal. L'adoption du cuivre arsénié, principalement en Irlande, fut suivie par celle du bronze (alliage de cuivre et d'étain) autour de 2200 av. J.-C. Cependant, alors que la mine de cuivre de Ross Island en Irlande date très certainement du début de l'âge du Bronze et que d'autres mines en Grande-Bretagne ont été attribuées au Bronze Ancien ou Moyen, les données concernant l'exploitation de l'étain, le second ingrédient indispensable à la fabrication du bronze, restent conjecturelles. Dans cet article, les auteurs présentent leurs analyses de la fluorescence des rayons X par instrument portable (pXRF) et

des microtraces d'usure conduites sur sept objets en pierre provenant de contextes bien datés. Les résultats fournissent de solides indications que ces objets avaient été utilisés dans le traitement de la cassitérite et documentent que l'étain provenant des Cornouilles avait été exploité dans les toutes premières phases de l'utilisation des métaux en Grande-Bretagne et en Irlande. Translation by Madeleine Hummler
Mots-clés : Campaniforme, Cornouailles, cassitérite, microtraces, métallurgie, traitement de minerai

Die Glockenbecherzeitliche und frühbronzezeitliche Ausbeutung von Zinn in Cornwall: Mikroverschleiß- ***und*** **Röntgenfluoreszenzanalysen identifizieren die Verarbeitung von Kassiterit**

Das Vorkommen der Glockenbecherkeramik in Großbritannien und Irland während des fünfundzwanzigsten Jahrhunderts v. Chr. kennzeichnet ein wichtiger archäologischer Horizont, der mit den ersten Metallartfakten übereinstimmt. Die Aufnahme von Arsenkupfer, meist aus Irland, wurde um ca. 2200 v. Chr. durch den Gebrauch von Zinnbronze ersetzt. Jedoch, obwohl das Kupferbergwerk von Ross Island in Irland sicher frühbronzezeitlich ist und andere solche Bergwerke in Großbritannien in die Früh- oder Mittelbronzezeit datiert werden, bleiben die Nachweise, dass Zinn—das zweite Hauptelement in der Herstellung von Bronze—ausgebeutet wurde, gering. In diesem Artikel legen die Verfasser die Ergebnisse der Analysen von sieben Steingegenständen aus sicher datierten Kontexten vor. Die Kombination von Mikroverschleiß-Untersuchungen und pRFA-Analysen liefern aussagekräftige Hinweise, dass diese Steingeräte zur Verarbeitung von Kassiterit dienten. Die Resultate zeigen, dass Zinn aus Cornwall zu den ersten Stufen der Verwendung von Metall in Großbritannien und Irland gehört. Translation by Madeleine Hummler
Stichworte: Glockenbecher, Cornwall, Kassiterit, Mikroverschleiß, Metallurgie, Erz-Bearbeitung

Figure captions

Figure 1. *Location of the two Beaker-period and one Early Bronze Age archaeological sites at national (A), regional (B), and sub-regional (C) scales.*

Figure 2. *Sennen PS07: plan of Structure 108, with location of key artefacts from this analysis highlighted.*

Figure 3. *A) Lelant (TR18) pit [6] post excavation working shot; B) Truro: simplified sections of pits [2447] and [3417]; C) pit [2447] during excavation (left) and pit [3417] covered by artefact S29 (right).*

Figure 4. *Stone tools presented in this analysis (shown at different scales, all scale bars 3 cm).*

Figure 5. *Key examples of macro- and microwear traces observed on the analysed tools: A) levelling of the surface topography (PS07-SF3); B) microfractures of grain crystals (indicated by arrow) (PS07-SF2); C) grain edge rounding (indicated by arrow) (TS18-S1); D) linear traces in the form of parallel, closely distributed striations (PS07-SF5); E) patches of highly reflective micropolish (taken at × 100) (PS07-SF5); F) patch of flat, reflective, striated micropolish (taken at × 200) (TS18-S1) (see Supplementary Material for full analyses).*

Figure 6: *Simplified chaine opératoire of tin processing. The evidence from our work pertains to phase 1 and phase 2. Phase 3 remains necessarily speculative given the evidence presented in this paper, although the association of tools with evidence of heating at Sennen (PS07) is suggestive.*

Tables

Table 1. *The tools analysed: lithology, size, and associated pottery (see also Figure 4).*

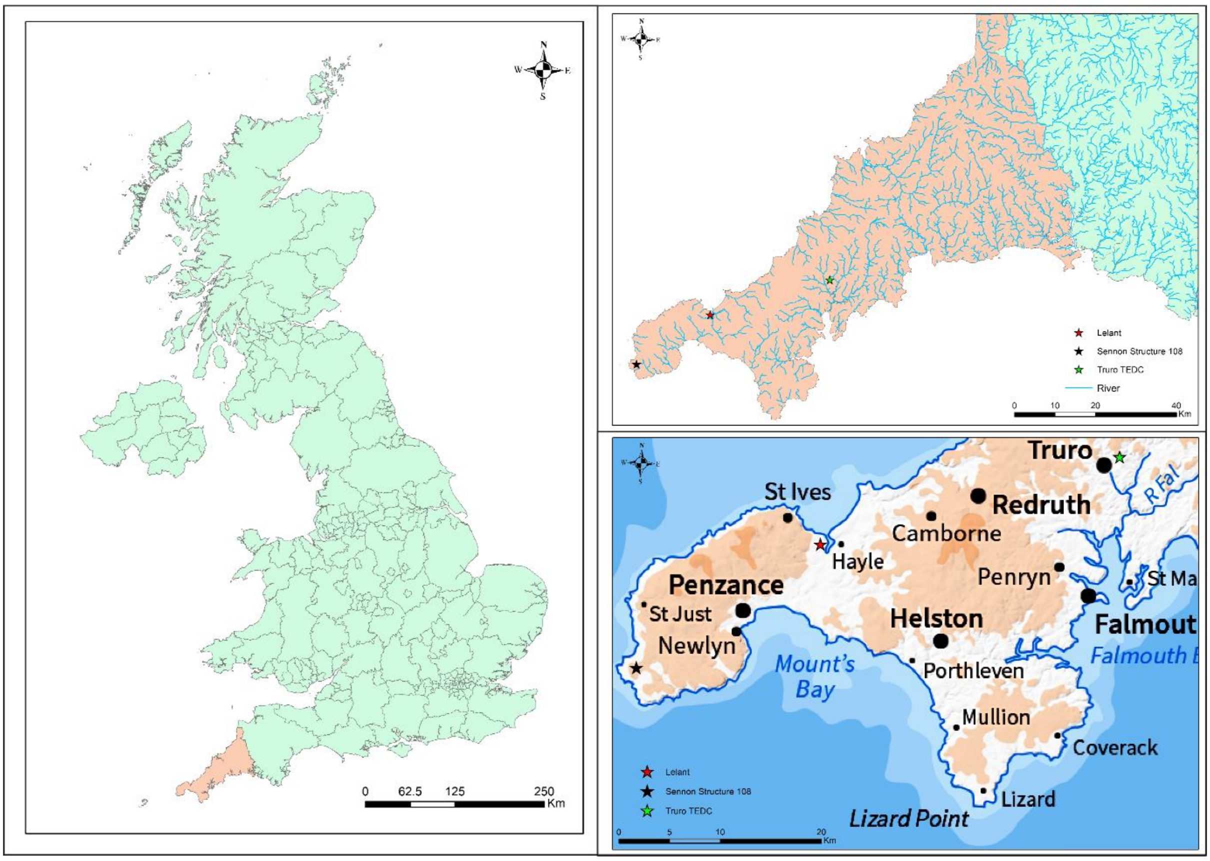
Artefact	**Lithology**	**Weight (g)**	**Dimensions: max. length, width, thickness (mm)**	**Object type and key features**	**Excavated context**	**Associated pottery**
Sennen SF33	Greenstone cobble; polish around girth	390	69.39 × 65.43 × 54.94	Pestle/pounder, abrading and pounding wear on two opposite ends	Context (101) upper fill of hearth [105] in pit [127]	Beaker
Sennen SF18	Beach cobble; fine grained granite with quartz and tourmaline	533	94.74 × 76.78 × 56.49	Grinding/pounding tool, abrasive and pounding wear traces on one broad surface and on both narrow ends	Context (89) upper fill of Structure 108	Beaker
Sennen SF5	Greenstone beach cobble	500	111.09 × 66.56 × 36.21	Grinding/pounding tool with finger grips on margins, abrasive and pounding wear on both broad surfaces, pounding wear on both narrow ends	Context (89) upper fill of Structure 108	Beaker
Sennen SF3	Greenstone beach cobble	658	126.31 × 78.12 × 37.26	Grinding/pounding tool with finger grip on one margin, abrasive and pounding wear on the broad surfaces,	Context (89) upper fill of Structure 108	Beaker

				percussive wear on narrow ends		
Sennen SF2	Quartzite cobble	743	116.50 × 77.41 × 60.80	Percussive tool with hafting hollows on margins and body, percussive wear on both narrow ends	Context (89) upper fill of Structure 108	Beaker
Lelant TR18 S1	Greenstone cobble	647	104.13 × 76.65 × 40.48	Grinding/percussive tool, grinding and pounding wear on broad faces, intentionally polished surface	Pit [6]	Curated Beaker pottery vessel
Truro TEDC S29	Gramscatho sandstone	2684	186.00 × 165.00 × 56.00	Lower (stable) grinding tool, abrasive wear on broad surface	Pit [3414]	Trevisker and Collared Urn pottery

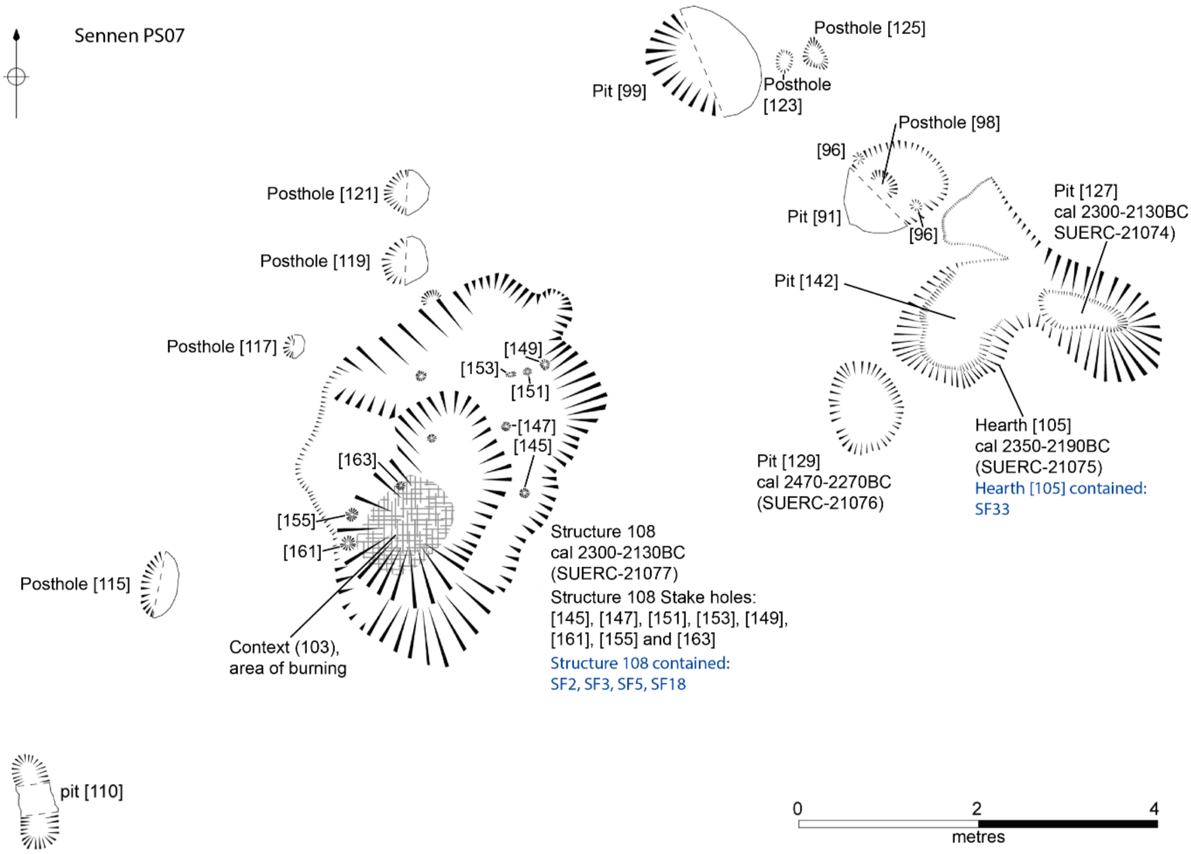
Table 2. *Analysed stone tools: key evidence and confidence of the interpretation (see also highlights on Figure 5 and online Supplementary Material).*

Artefact	pXRF evidence	Microwear analysis	Key interpretations	Confidence in interpretation and relationship to metalworking
Sennen SF33	Very high Sn and Arsenic (As) measurements on both working ends of the tool. Sn mineralisation also visible on the interior of drilled core. Object recorded as a greenstone, but contains an anomalous geochemical signature	Step fractures and edge rounding on crystal grains, patches of reflective micropolish on higher elevations of crystal grains. Wear development including the creation of facets on the opposite ends suggests use with a rotational motion	Tool used for grinding/crushing small-sized particles of a medium hard mineral. Some elevation of Sn and As on the working ends, although elevated Sn and As is also a natural component of the tool lithology	High
Sennen SF18	Sn measurements slightly elevated on the working ends	Levelling of crystal grains associated with striations and grain extraction, patches of reflective micropolish, impact fractures with a pointed morphology and crushing on the higher elevation of the grains, occasionally edge rounding and micropolish	Tool used for grinding and pounding/pulverising semi-hard material of mineral origin, interpreted as cassiterite	Medium–high
Sennen SF5	Slight Sn elevations recorded on use faces and ends	Levelling of grains, associated with striations and grain extraction, patches of highly reflective, striated micropolish. Both ends exhibit grain extraction and occasional grain edge rounding consistent with pounding actions	Tool used to reduce and pulverise larger fragments of semi-hard mineral material into smaller, finer particles, interpreted as cassiterite	Medium–high
Sennen SF3	Moderate elevations of Sn	Levelling of grains associated with striations and grain extraction, patches of highly reflective, striated micropolish, grains with step	Tool used to reduce and pulverise larger fragments of semi-hard mineral matter into smaller, finer particles interpreted as cassiterite	High

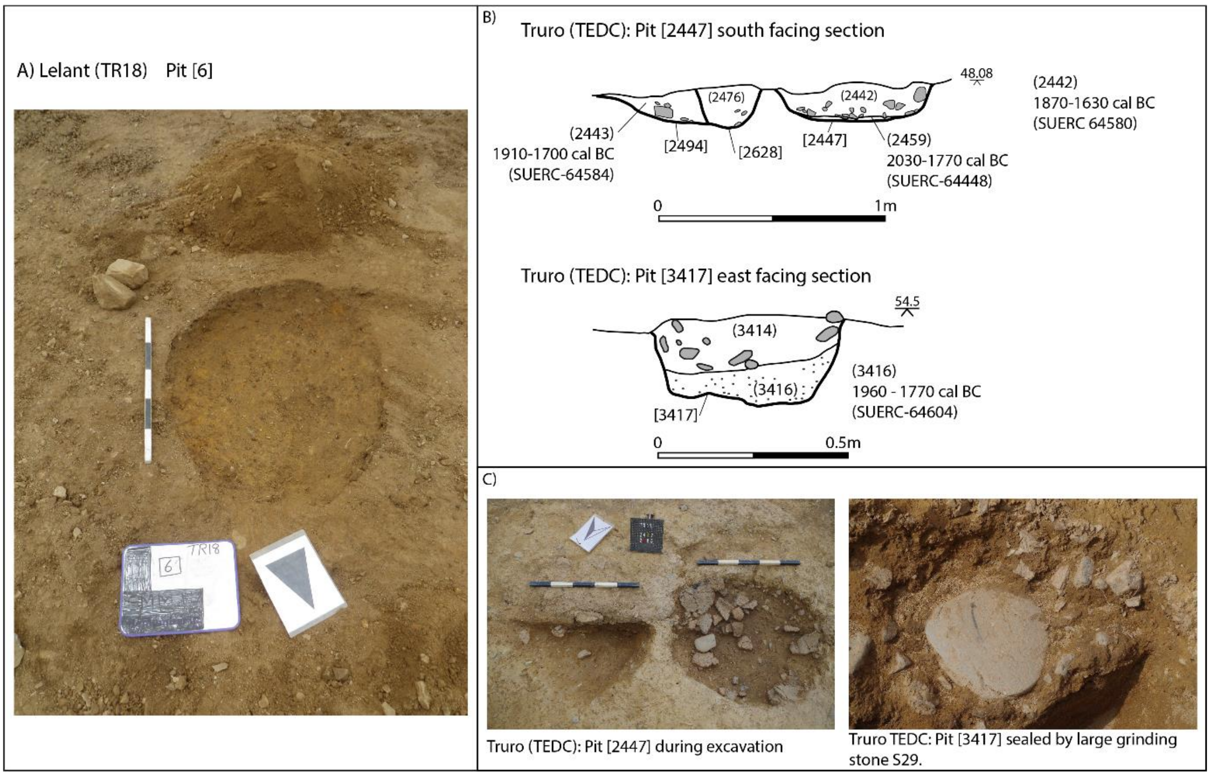
		fractures or pointed morphology, grain extraction and occasional grain edge rounding		
Sennen SF2	No Sn or As detected on tool surface	Wear traces include grain extraction and grain fractures with a pointed morphology and step fractures on the highest elevation of the crystal grains, patches of flat micropolish. The location and microwear signatures indicate pounding against a hard mineral material	Possible tool use to break up larger nodules of cassiterite into smaller fragments, however the use on another mineral material also possible. No detectable Sn	Medium
Lelant TR18 S1	Sn and As elevated on the working surfaces	Levelling of the topography accompanied by striations, grain removal and fractures, patches of highly reflective, striated micropolish, well-developed micropolish of flat topography and smooth texture and multi-directional striations resulting from the intentional polishing of the surface of the stone tool. Both ends show grain edge rounding, occasional microfractures of pointed morphology and micropolish	Tool used for grinding and pounding cassiterite and possibly for smoothing and shaping metallic (tin?) objects. No Cu was detected by the pXRF, therefore no direct evidence for smoothing/shaping Bronze	High
Truro TEDC S29	Extremely high and high measurements of Sn	Levelling of the topography accompanied by striations, and limited grain removal and fractures, small patches of reflective micropolish on the higher elevations of the microtopography	Tool used as a lower (stable) grinding tool for processing cassiterite ore prior to smelting. Tool was found with cassiterite pebbles and angular fragments of processed cassiterite	Extremely high



0 62.5 125 250 Km
Lelant
Sennon Structure 108
Truro TEDC
River
0 10 20 40 Km
Truro
R Fal
St Ives
Redruth
Camborne
Hayle
Penzance
Penryn
St Ma
St Just
Falmout
Helston
Newlyn
Mount's Bay
Falmouth B
Porthleven
Mullion
Coverack
Lizard
Lizard Point
0 5 10 20 Km



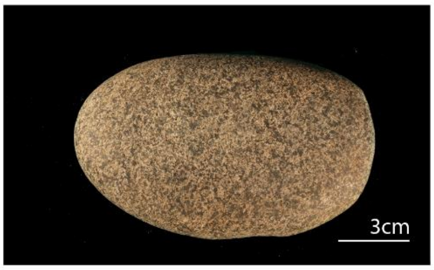
Sennen PS07
Posthole [125]
Pit [99]
Posthole [123]
Posthole [98]
[96]
Pit [91]
[96]
Pit [127]
cal 2300-2130BC
SUERC-21074)
Posthole [121]
Posthole [119]
Pit [142]
Posthole [117]
[149]
[153]
[151]
[147]
[145]
[163]
[155]
[161]
Hearth [105]
cal 2350-2190BC
(SUERC-21075)
Hearth [105] contained:
SF33
Pit [129]
cal 2470-2270BC
(SUERC-21076)
Structure 108
cal 2300-2130BC
(SUERC-21077)
Structure 108 Stake holes:
[145], [147], [151], [153], [149],
[161], [155] and [163]
Structure 108 contained:
SF2, SF3, SF5, SF18
Posthole [115]
Context (103),
area of burning
pit [110]
0 2 4
metres



PS07: SF33 Face B

PS07: SF18 Face A

PS07: SF5 Face B

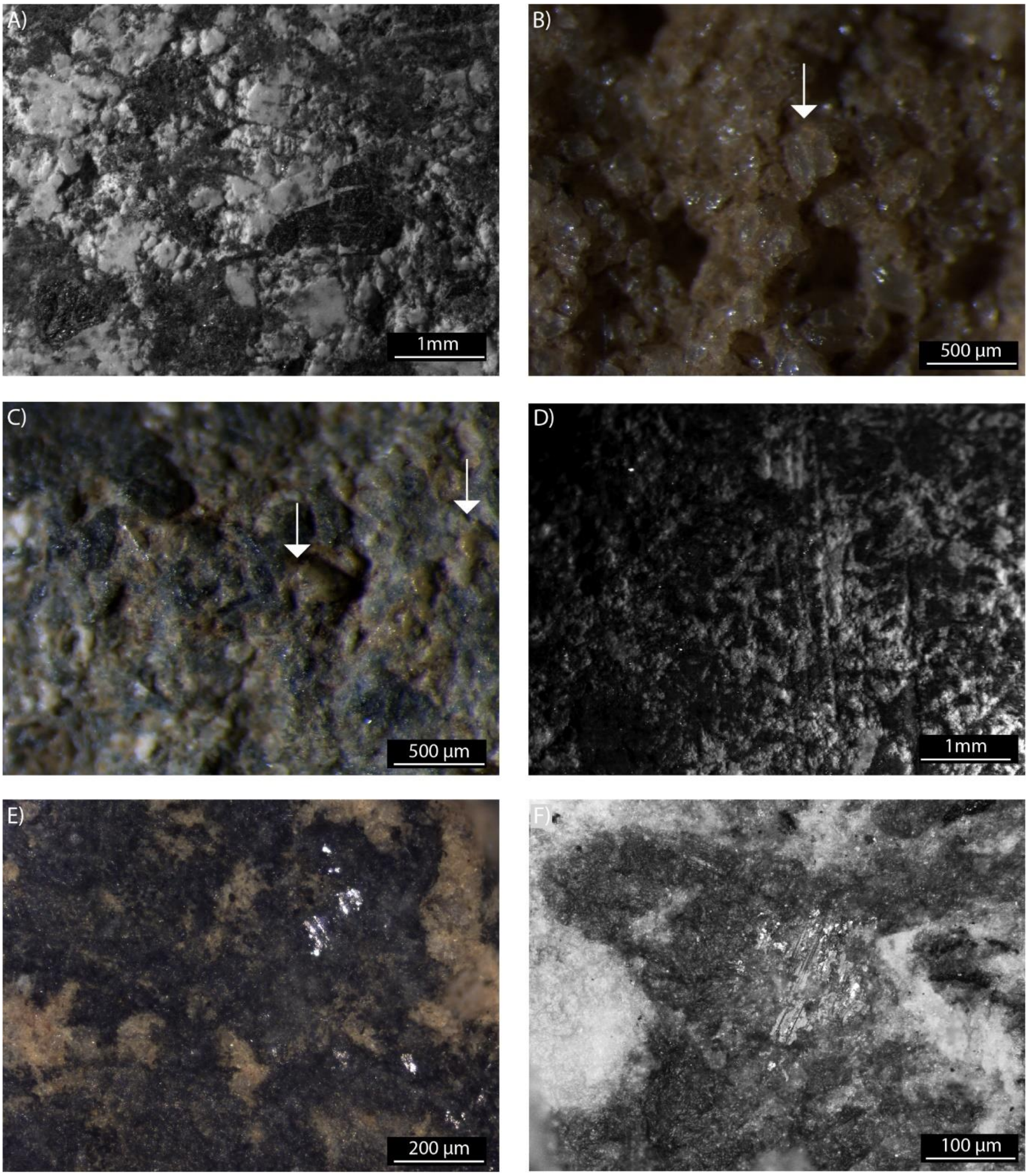


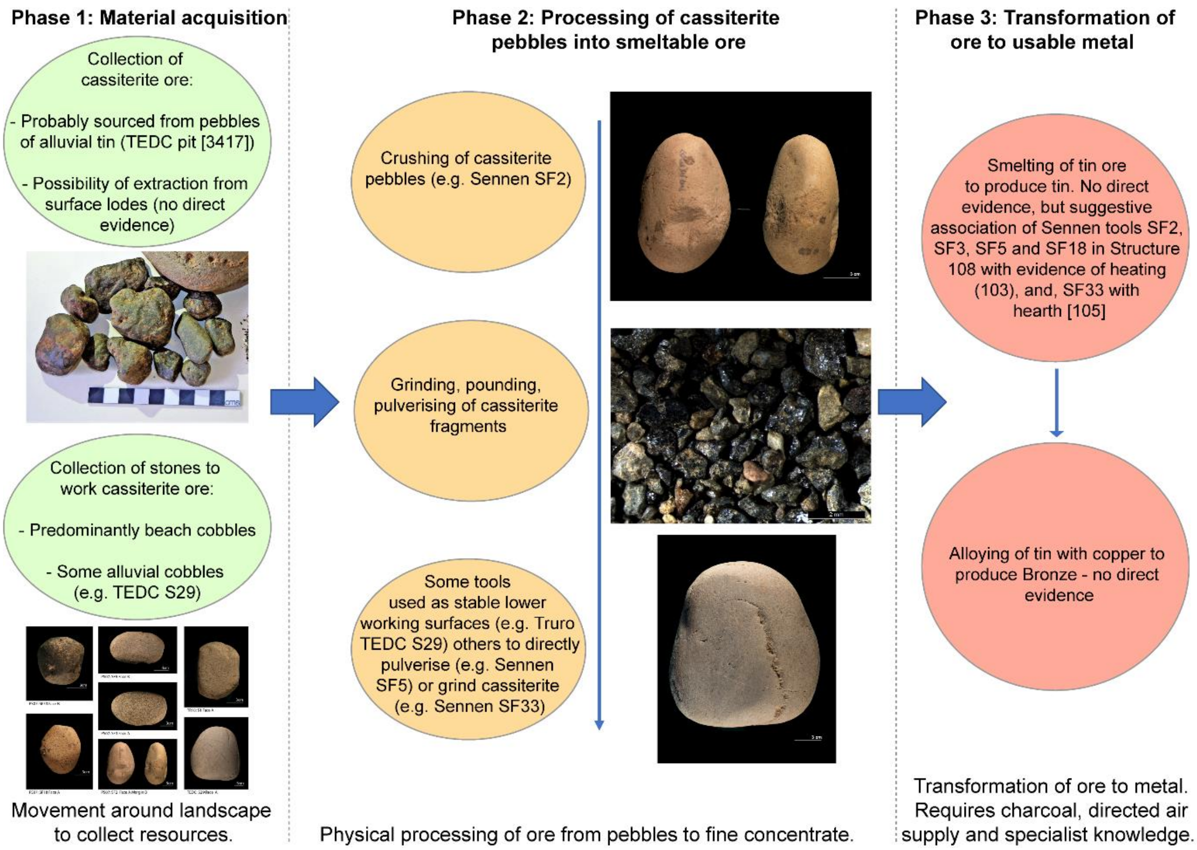
PS07: SF3 Face A

PS07: SF2 Face A Margin B

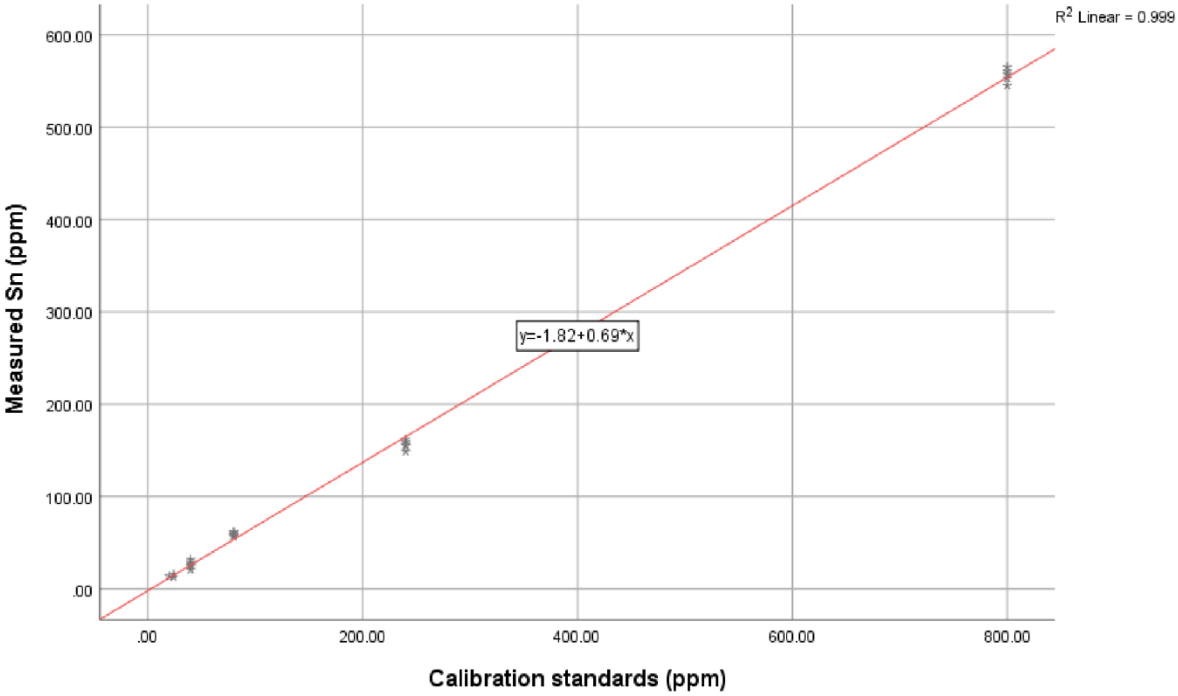
TR18: S1 Face A

TEDC: S29 Face A


A)
1mm
B)
500 µm
C)
500 µm
D)
1mm
E)
200 µm
F)
100 µm


Phase 1: Material acquisition
Collection of cassiterite ore:
- Probably sourced from pebbles of alluvial tin (TEDC pit [3417])
- Possibility of extraction from surface lodes (no direct evidence)
Collection of stones to work cassiterite ore:
- Predominantly beach cobbles
- Some alluvial cobbles (e.g. TEDC S29)
Movement around landscape to collect resources.
Phase 2: Processing of cassiterite pebbles into smeltable ore
Crushing of cassiterite pebbles (e.g. Sennen SF2)
Grinding, pounding, pulverising of cassiterite fragments
Some tools used as stable lower working surfaces (e.g. Truro TEDC S29) others to directly pulverise (e.g. Sennen SF5) or grind cassiterite (e.g. Sennen SF33)
Physical processing of ore from pebbles to fine concentrate.
Phase 3: Transformation of ore to usable metal
Smelting of tin ore to produce tin. No direct evidence, but suggestive association of Sennen tools SF2, SF3, SF5 and SF18 in Structure 108 with evidence of heating (103), and, SF33 with hearth [105]
Alloying of tin with copper to produce Bronze - no direct evidence
Transformation of ore to metal. Requires charcoal, directed air supply and specialist knowledge.

Sn (ppm)					
Calibration	Mean	Minimum	Maximum	Std. Deviation	Detection
20.00	14.0000	14.00	14.00	-	1 in 5
24.00	14.5000	13.00	16.00	2.12	3 in 5
40.00	26.8000	21.00	32.00	4.15	5 in 5
80.00	59.4000	57.00	62.00	2.07	5 in 5
240.00	156.2000	149.00	162.00	4.87	5 in 5
800.00	556.0000	545.00	565.00	7.55	5 in 5
Total	175.4348	13.00	565.00	211.28	5 in 5

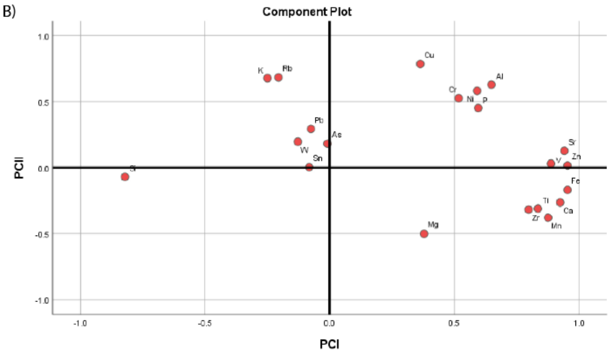


A)

	Component				
	1	2	3	4	5
Mg	.379	-.501	.447	.154	.023
Al	.648	.629	-.037	.216	-.265
Si	-.821	-.069	-.135	-.313	.042
P	.595	.452	-.342	-.218	.252
K	-.250	.678	.657	.022	.030
Ca	.924	-.263	.147	-.063	.107
Ti	.835	-.310	.255	.070	-.088
V	.888	.031	.270	-.049	-.017
Cr	.517	.526	-.281	-.345	.399
Mn	.876	-.379	.145	.056	.044
Fe	.954	-.169	.013	.131	-.117
Ni	.591	.582	-.371	-.247	.226
Cu	.364	.785	-.138	.047	-.310
Zn	.954	.016	-.045	.073	-.037
As	-.008	.182	-.441	.560	-.544
Rb	-.205	.683	.652	-.013	-.011
Sr	.941	.127	.057	-.010	-.046
Zr	.798	-.317	-.076	-.010	.060
Sn	-.082	.003	-.122	.750	.604
W	-.128	.196	-.235	.903	.199
Pb	-.075	.292	.807	.226	.129

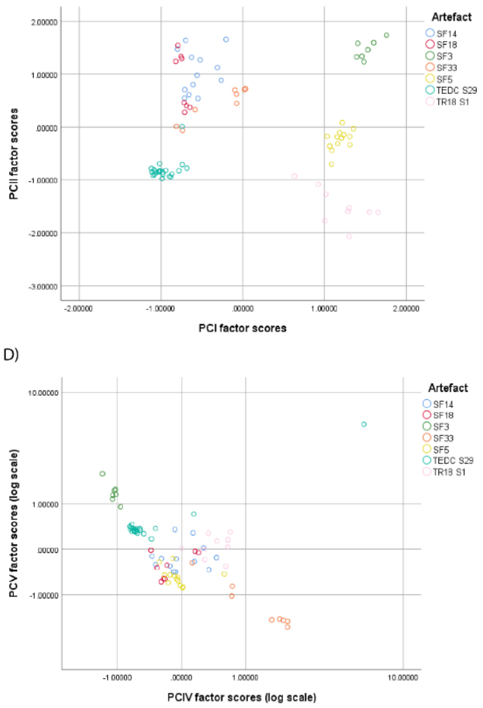
Extraction Method: Principal Component Analysis.
a. 5 components extracted.

B)

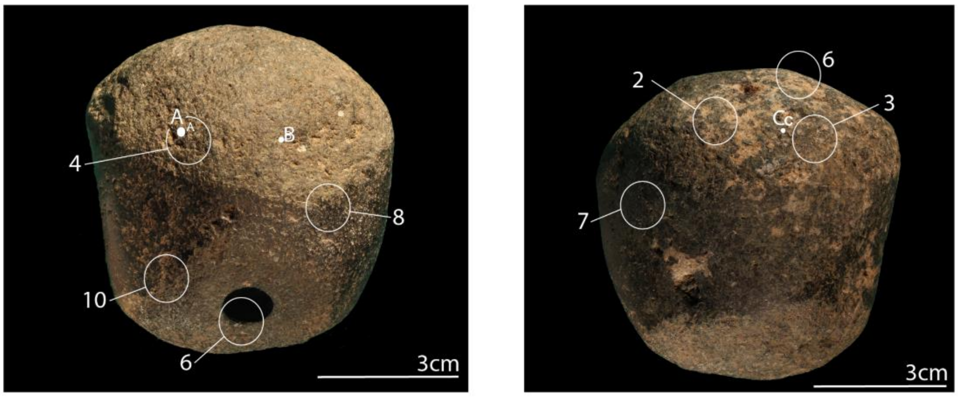


C)

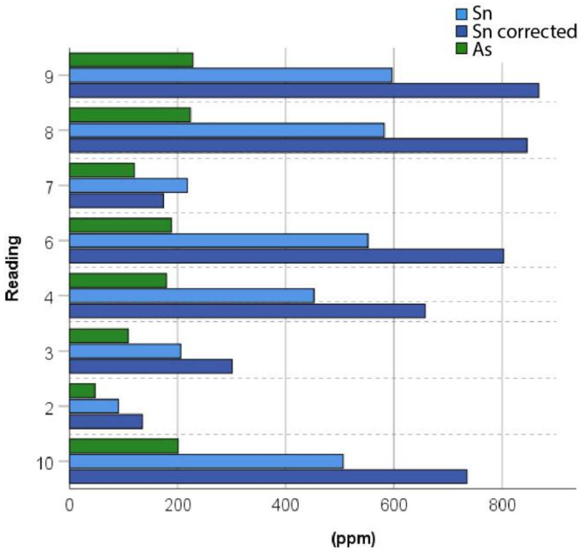
D)

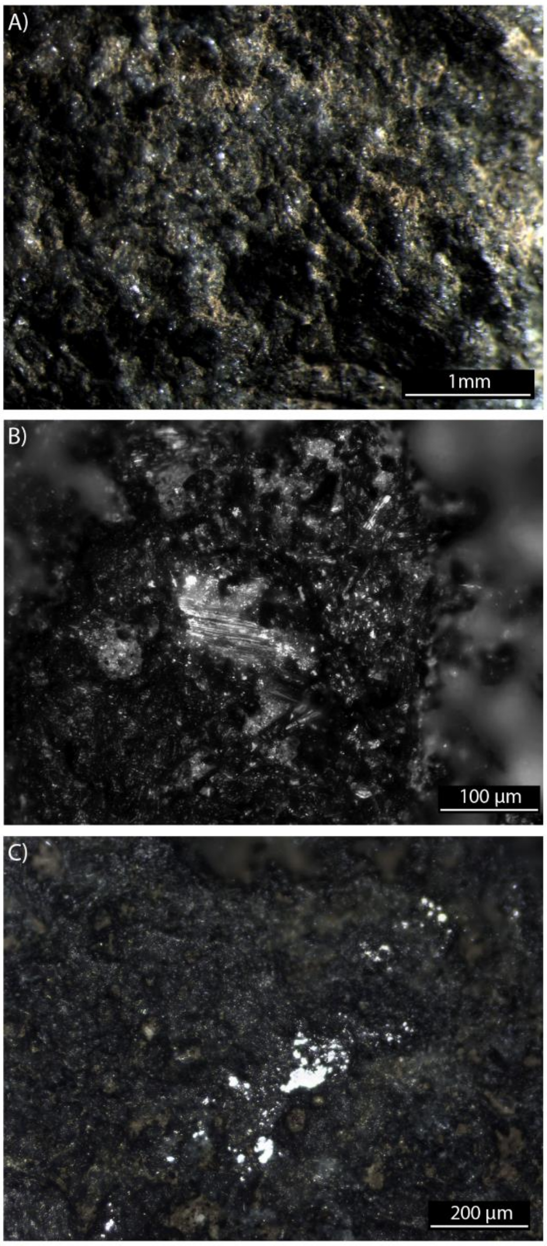


PSO7
SF33

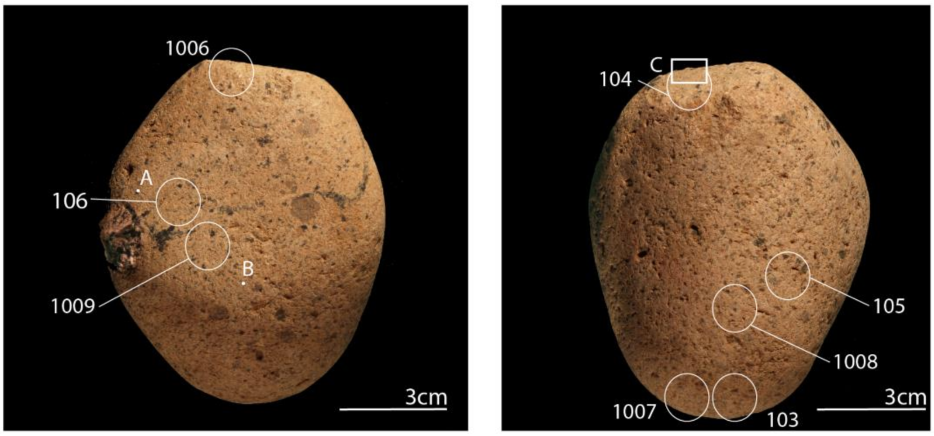


Reading	As (ppm)	Original Sn / Corrected Sn (ppm)
2	47	91/135
3	109	206/301
4	179	452/658
6	189	552/803
7	120	218/174
8	224	582/846
9	228	597/868
10	201	506/735

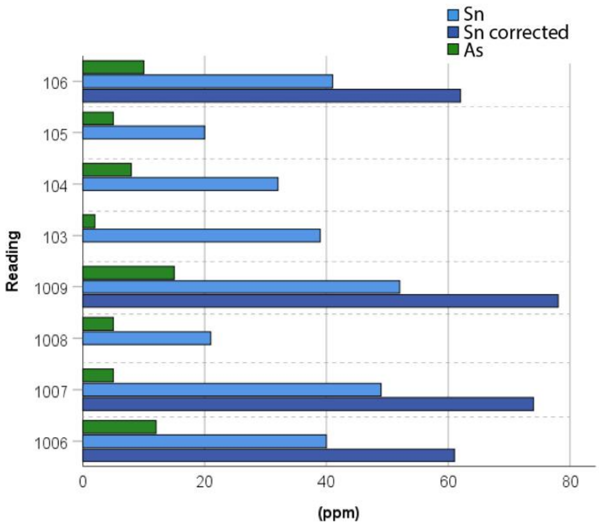


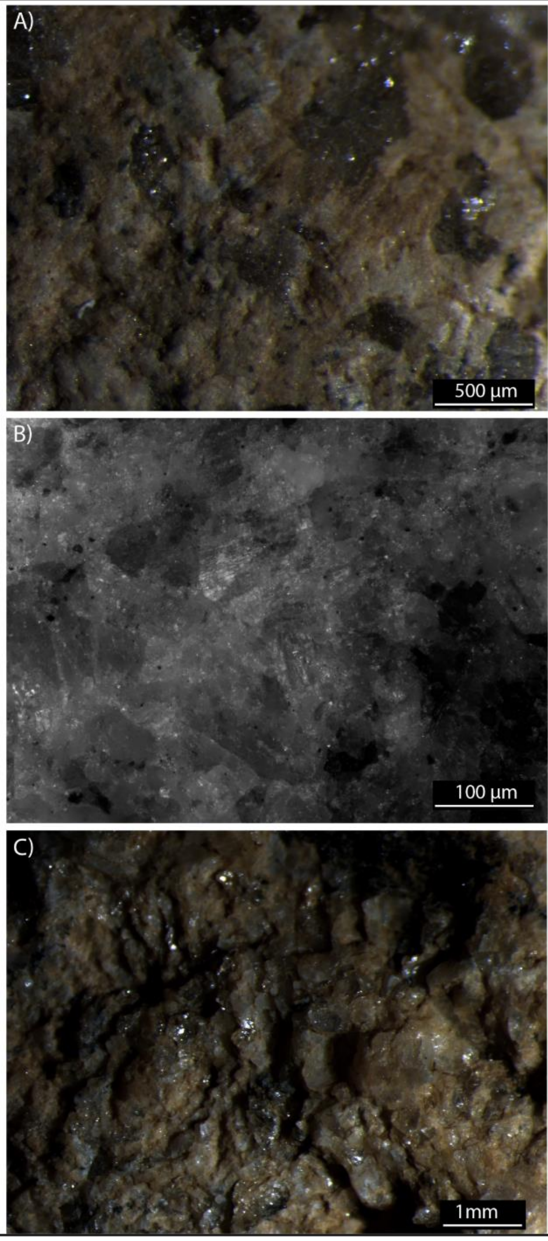


PSO7
SF18

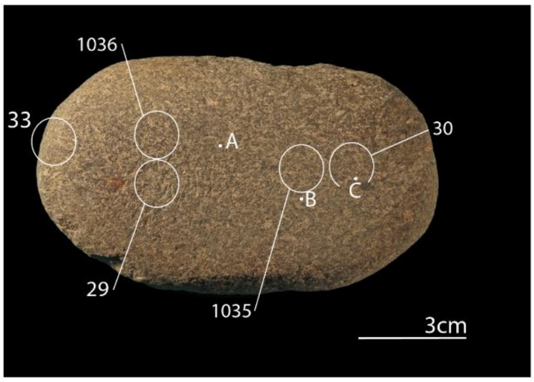


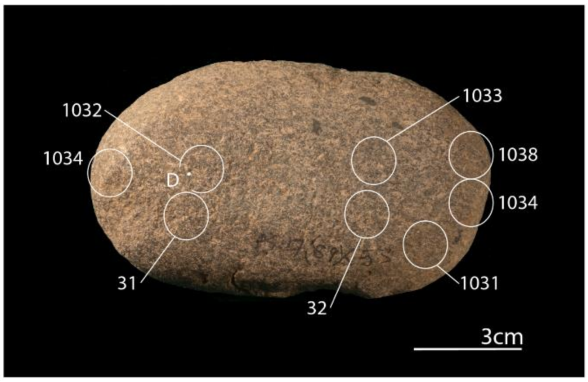
Reading	As (ppm)	Original Sn / corrected Sn (ppm)
103	2	39
104	8	32
105	5	20
106	10	41/62
1006	12	40/61
1007	5	49/74
1008	5	21
1009	15	52/78



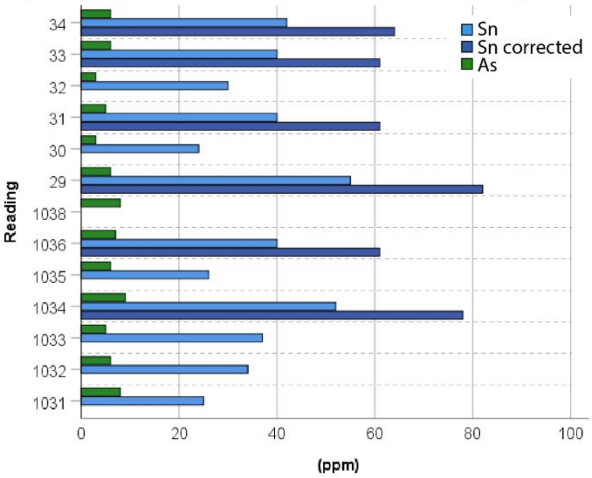


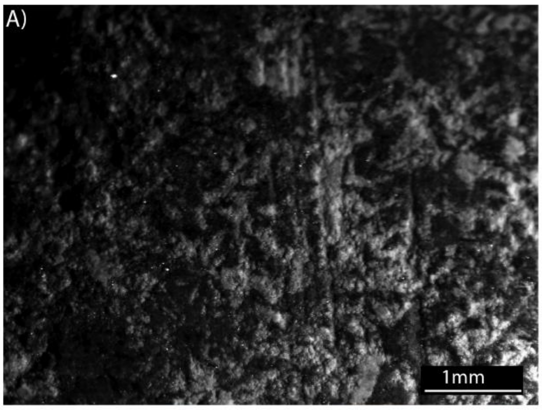
PSO7 SF5

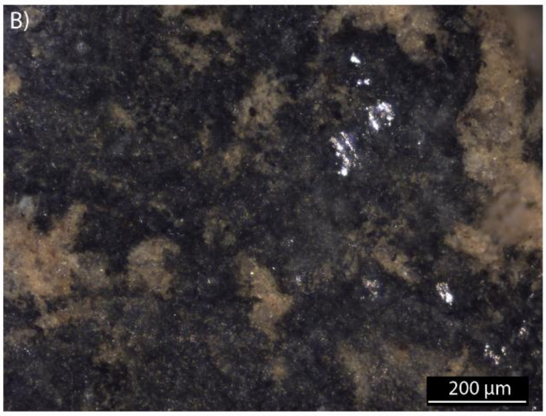


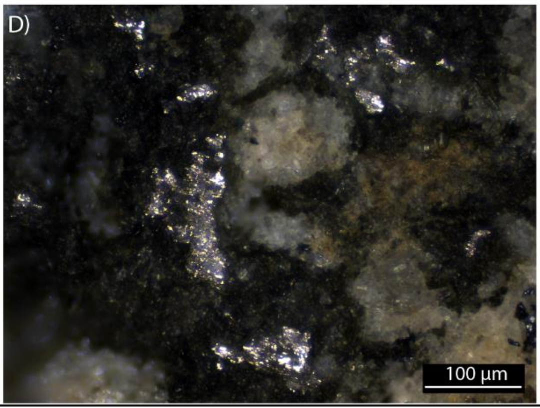


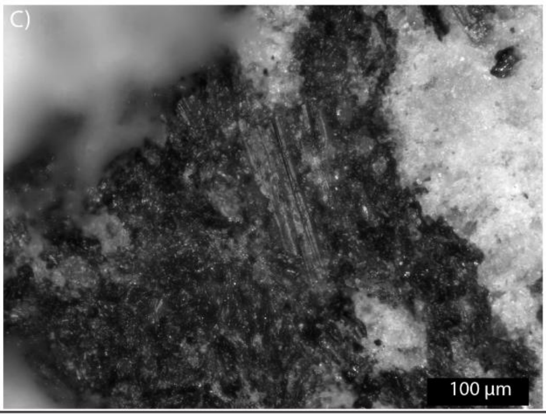
Reading	As (ppm)	Original Sn / corrected Sn (ppm)
1031	8	25
1032	6	34
1033	5	37
1034	9	52/78
1035	6	26
1036	7	40/61
1038	8	-
29	6	55/82
30	3	23
31	5	40/61
32	3	30
33	6	40/61
34	6	42/64



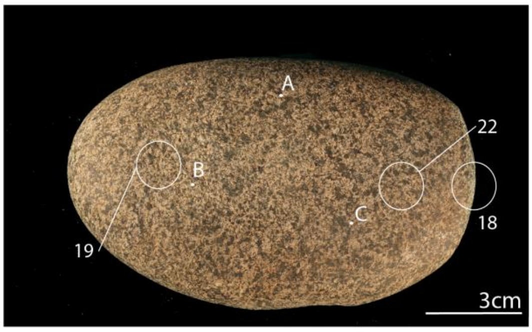




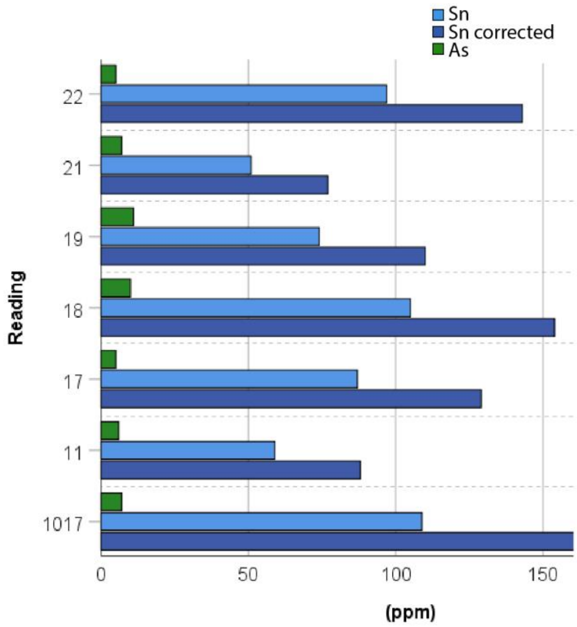


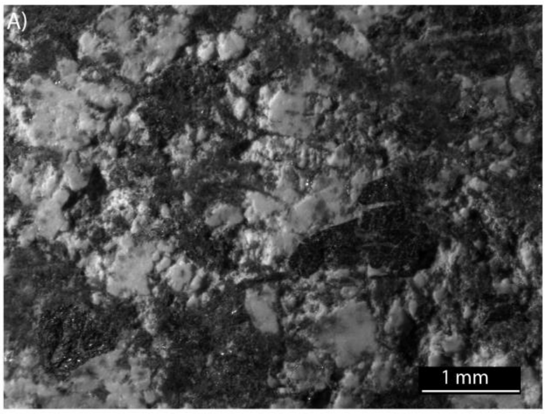


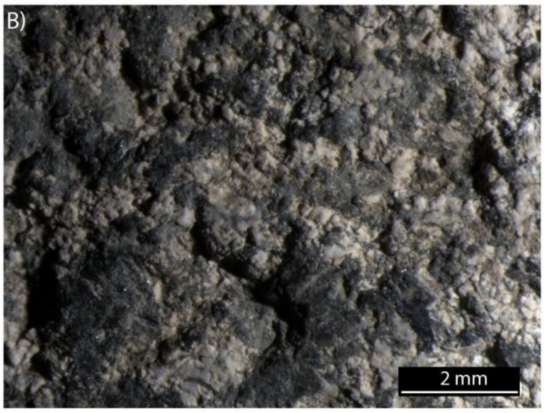
PSO7 SF3

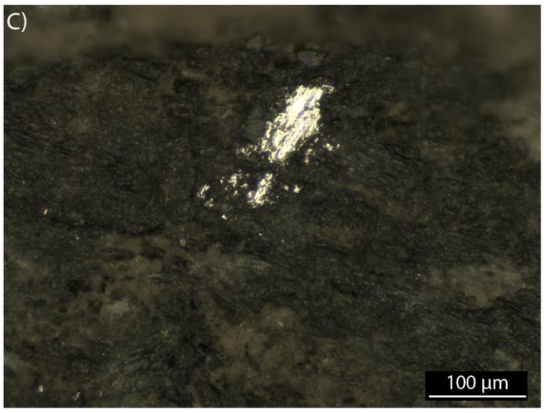


Reading	As (ppm)	Original Sn / Corrected Sn (ppm)
11	6	59/88
17	5	87/129
18	10	105/154
19	11	74/110
21	7	51/77
22	5	97/143
1017	7	109/161



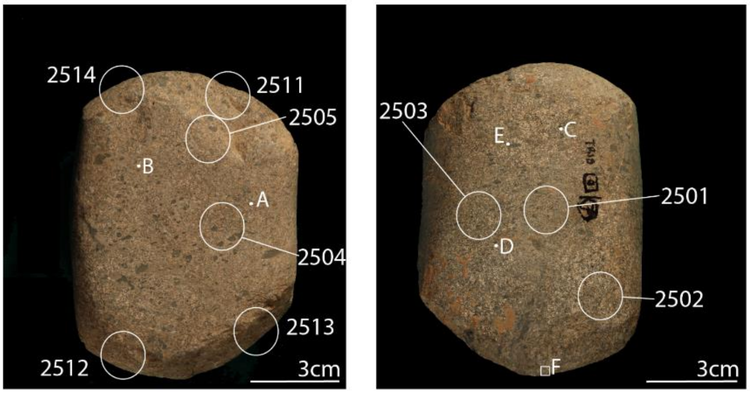




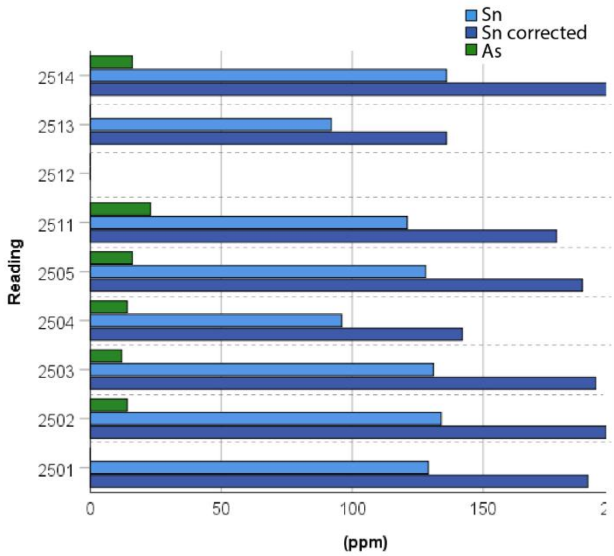


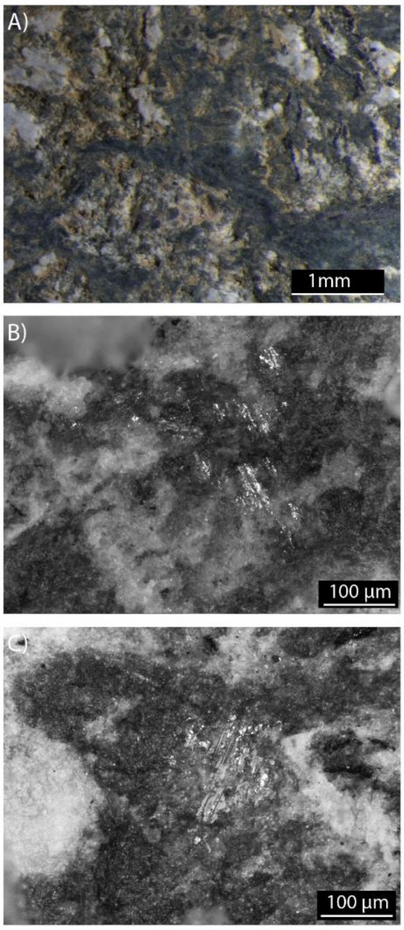
PSO7 SF2

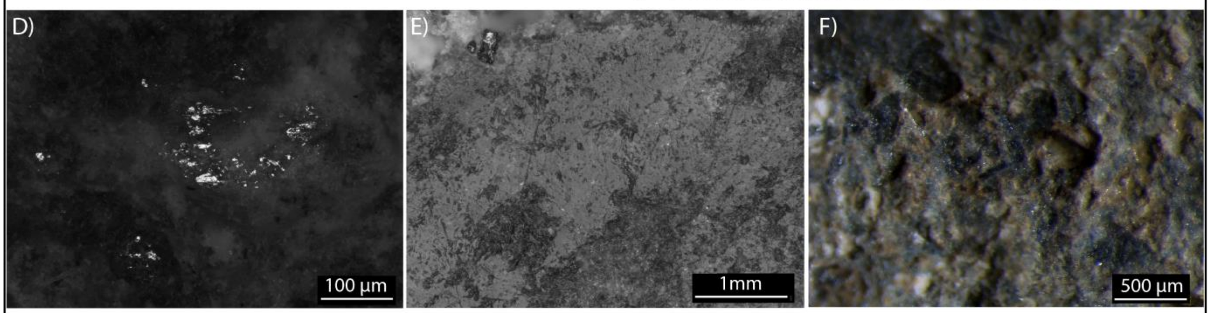
TR18 S1



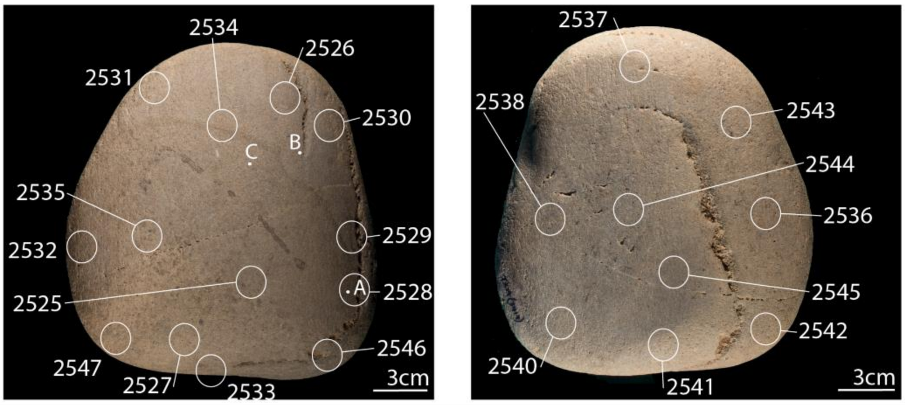
Reading	As (ppm)	Original Sn / Corrected Sn (ppm)
2501	-	129/190
2502	14	134/197
2503	12	131/193
2504	14	100/142
2505	16	128/188
2511	23	121/178
2512	-	-
2513	-	92/136
2514	16	136/200



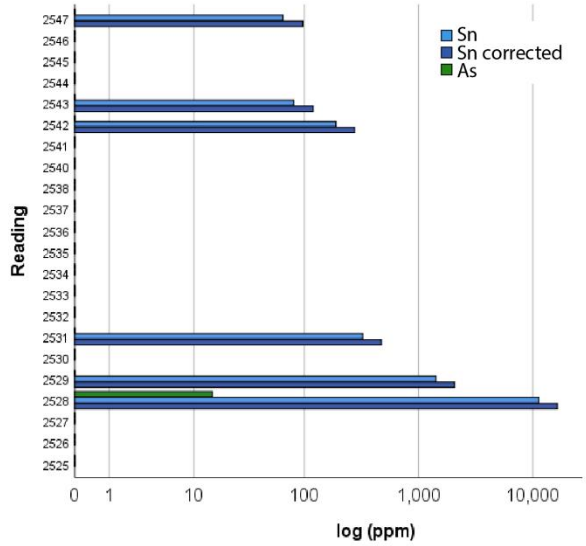


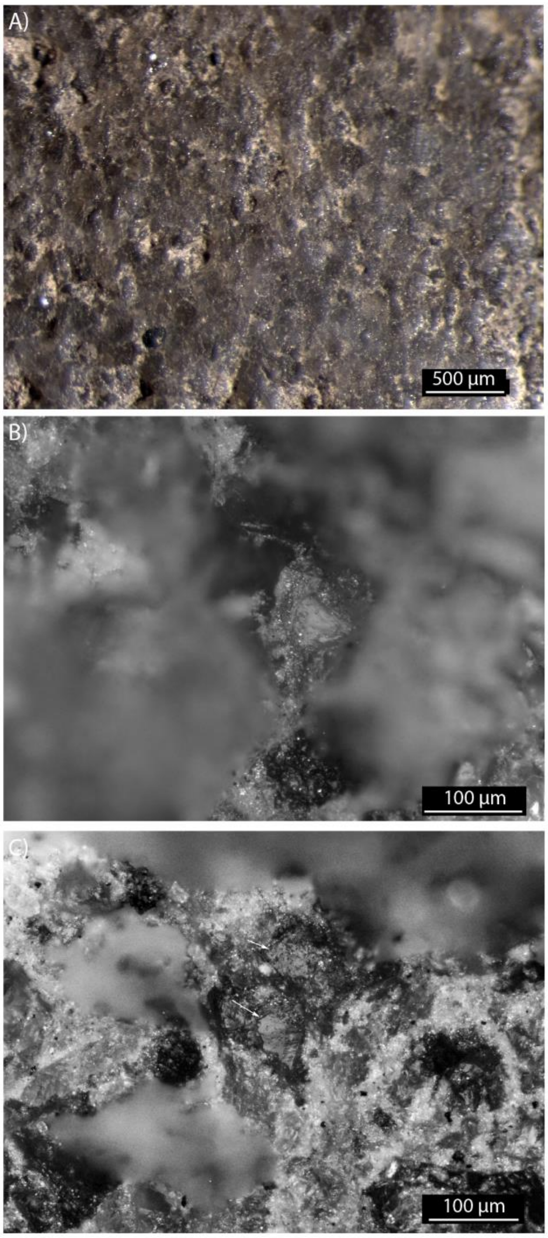


TEDC S29



Reading	As (ppm)	Original Sn / Corrected Sn (ppm)
2525	-	-
2526	-	-
2527	-	-
2528	15	11315/16401
2529	-	1427/2071
2530	-	-
2531	-	327/477
2532	-	-
2533	-	-
2534	-	-
2535	-	-
2536	-	-
2537	-	-
2538	-	-
2540	-	-
2541	-	-
2542	-	190/278
2543	-	81/120
2544	-	-
2545	-	-
2546	-	-
2547	-	65/97





Beaker and Early Bronze Age Tin Exploitation in Cornwall: Cassiterite Processing Identified through Microwear and pXRF Analyses

CHRIS CAREY, CHRISTINA TSORAKI, ANDY M. JONES, OLIVER J.T. HARRIS, RACHEL J. CRELLIN AND PETER LYONS

SUPPLEMENTARY MATERIAL

The supplementary information provides the specialist detail of the work conducted and a detailed discussion of the geochemical and microwear results of each object. Initially, the stone tools were analysed by pXRF; whilst the results obtained were highly suggestive, they did not provide an unequivocal interpretation of tool use. Subsequently, the opportunity arose to analyse a selection of the stone tools by microwear analysis, which strengthened and refined the interpretations of the use of a selected range of the stone tools.

METHODOLOGY

Portable X-Ray Florescence analysis

Portable X-Ray Florescence (pXRF) analysis is frequently used for non-destructive analysis of archaeological materials, particularly metal artefacts (Charalambous et al., 2014), as well as lithic materials (e.g. Markham & Floyd, 1998; Nash et al., 2020). Both Killick (2015) and Torrence et al. (2015) consider the use of pXRF in archaeological investigations and note the lack of consistency between different surveys and instruments, with few studies comparing XRF-derived values with acid-based digestion and spectrometer analysis of element concentrations (e.g. Booth et al., 2017). Within this study, the geochemical data were used for intra-assemblage analysis only, with values taken as indicative rather than absolute. The true values of elements on the artefacts were less important than the relative change between artefacts (with the exception of Sn). In this sense, the data from this study is not used for comparison with other studies, using different instrumentation; instead it is used as a method of intra-assemblage analysis. However, the use of Certified Reference Materials (CRMs) has created a dataset that has internal consistency.

This analysis used a pXRF Innov-X Alpha Series™ instrument. Detection limits were in the order of 1–5ppm for heavy elements and 10–50ppm for lighter metals. The instrument employs a Compton Normalization that allows elements to be measured over a wide concentration range and corrects for matrix interference effects. However, the detection of Sn did require a greater reliability of measured concentrations in this analysis. To achieve this, bespoke tin calibration standards were made using a combination of tin powder (99.8%

purity) from Sigma Aldrich and Extra Pure Sand from Fisher Scientific, at 0ppm, 0.8ppm, 8ppm, 20ppm, 24ppm, 40ppm, 80ppm, 240ppm, 800ppm, and 8000ppm. Standards were homogenized and pressed into aluminium cups, using 8g of standard to 2g of wax binder. Each standard was subject to three readings of the same location, before two further readings on different locations on the same standard, using a 5-minute count time.

Initially, the stone tool assemblages from Sennen PS07 (fourteen artefacts), plus selected artefacts from Lelant TR18 (one artefact), Truro TEDC (one artefact) and also Penzance TZH18 (four artefacts not discussed further) had their surfaces analysed by pXRF, scanning for the detection of elements associated with metalliferous ores using a 3-minute reading time. When elements such as tin (Sn) were detected, the stone tools were subjected to a more detailed analysis using pXRF, using a 5-minute reading time, taking several readings across each artefact's surface, with surface reading locations recorded on a photograph of the artefact. Indicative measurements of Al, Si, P, K, Ti, V, Cr, Mn, Fe, Ni Cu, Zn, As, Rb, Sr, Sn, W, Zr, and Pb were recorded. In addition, two small cores were removed from SF33 and SF3 to compare Sn concentrations on the interior and exterior surface of the artefacts. Cores were removed with a diamond-tipped 12mm drill, drilling to a depth of *c*. 1 cm, with both the interior and exterior surfaces measured with the pXRF for a measurement time of 5 minutes. This procedure was stopped due to ambiguity in the results (see below) and the destructive nature of the process.

The geochemical data (excluding the readings from the cores) were analysed by Principal Component Analysis (PCA hereafter, using a Statistical Package for the Social Sciences or SPSS), using a correlation matrix, which allows the association between the elements (variables) and components (geochemical signatures) to be visualized (e.g. Frankel & Webb, 2012; Carey et al., 2014). Some elements had values that were not detectable (ND), which were substituted for zero, in order to complete a PCA of the data. Whilst this is a limitation of the pXRF used, the readings below detection level were low, with the subsequent substitution having little effect on the positioning of new components. However, this process was only used to define general signatures within the data, with both the original and calibrated concentrations of Sn compared to the microwear results.

From the initial pXRF scanning, seven artefacts revealed Sn concentrations, and these artefacts were subjected to further detailed analysis. Other elements associated with metalliferous ores, e.g. Cu were either largely absent, displayed little inter-correlation variance, or little variation either on or between artefacts. The pXRF could reliably detect Sn at 40ppm and above, with no detection below 20ppm, and variable detection at 20ppm and

24ppm (Figure S1). However, despite detection levels being good, the pXRF underestimated the concentration of Sn; therefore, for all artefacts (below), both original and corrected values from the regression model are presented for Sn.

Sn (ppm)					
Calibration	Mean	Minimum	Maximum	Std. Deviation	Detection
20.00	14.0000	14.00	14.00	-	1 in 5
24.00	14.5000	13.00	16.00	2.12	3 in 5
40.00	26.8000	21.00	32.00	4.15	5 in 5
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240.00	156.2000	149.00	162.00	4.87	5 in 5
800.00	556.0000	545.00	565.00	7.55	5 in 5
Total	175.4348	13.00	565.00	211.28	5 in 5

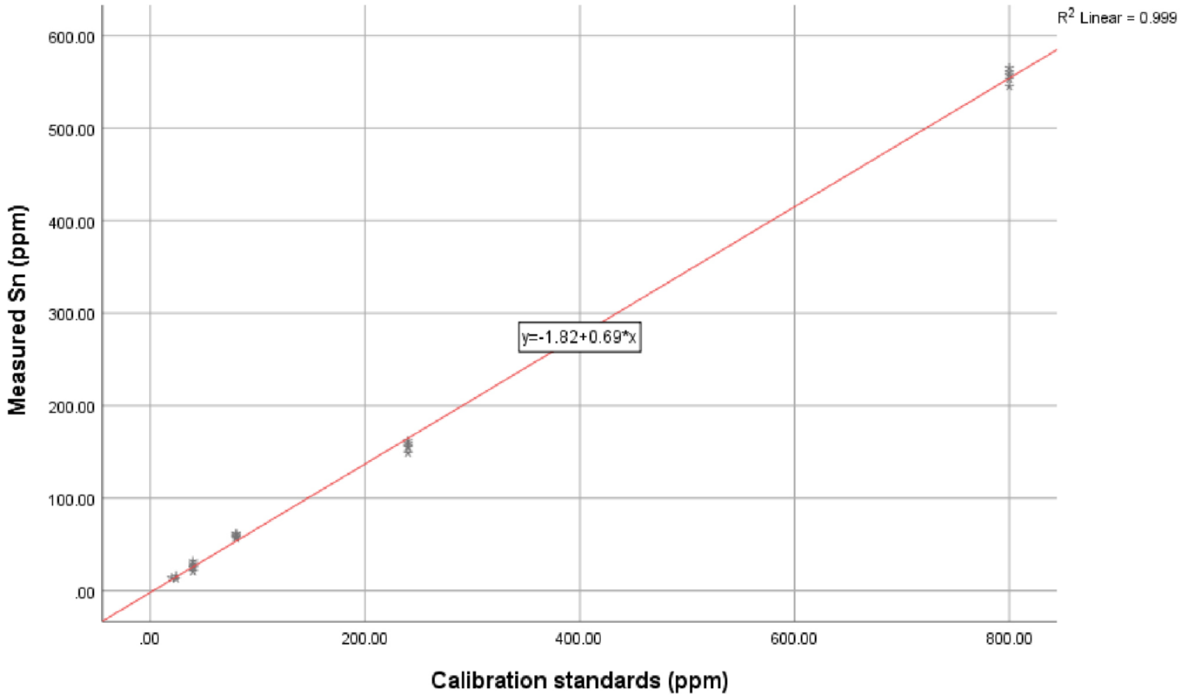
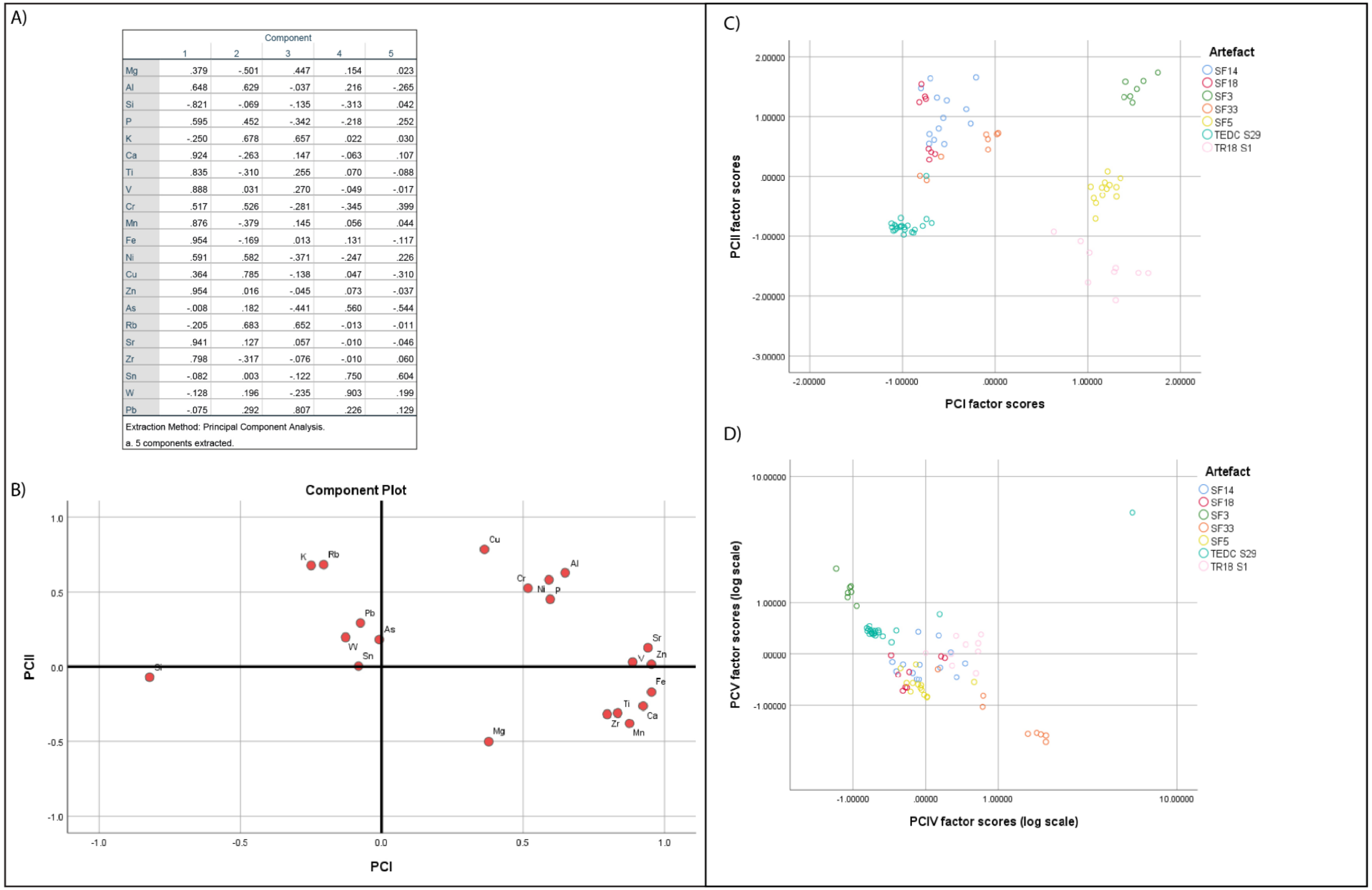


Figure S1. *Measurements of the Sn calibration standards and resultant regression line equation used to correct the original measurement values.*

The PCA used the original uncorrected Sn values and extracted five principal components (Figure S2 A), with PCI strongly associated with Al, Ca, Ti, V, Mn, Fe, Zn, Sr and Zr, and moderately associated with Ni and Cu. PCII was strongly associated with Al, K, Cu and Rb, and moderately associated with P, Cr and Ni. PCIII was strongly associated with K, Rb and moderately associated with Mg. PCIV was strongly associated with Sn and W, and a moderately associated with As, and PCV was strongly associated with Sn.

The PCI/PCII component plot shows Sn, As, W and Pb as distinct to the other elemental groupings (Figure S2 B), a signature associated with tin mineralization. The plotting of the individual reading factor scores for the first two components (Figure S2 C) shows that the greenstone artefacts (SF3, SF5, and TR18 S1) have high factor scores for PCI, defining a greenstone component. The granite artefacts (SF14 and SF18) have high factor scores for PCII, defining a granite component. Two stone tools, SF33 and TEDC S29, were identified as deriving from different lithologies. SF33 was originally identified as a greenstone and has low to negative factor scores for PCI and a range of factor scores for PCII, defining a greenstone variant with an anomalous geochemical composition (see below). TEDC S29 is a Gramscatho sandstone and has negative factor scores for both PCI and PCII. The PCIII factor scores are high for SF18 and TR18 S1, again defining a granitic signature associated with K, Rb and Pb, almost certainly feldspar (Heier, 1962).

PCIV is shown against PCV (Figure S2 D) and the artefacts SF33, SF14, TR18 S1, SF14, and two readings from SF18 and one reading from TEDC S29 have positive factor scores for PCIV; artefacts SF3, TEDC S29, and TR18, and three readings from SF14, and five readings from TR18 S1 having positive factor scores for the PCV. PCIV defines a geochemical signature associated with Sn mineralization (cassiterite), although the measurements of As and W were often at low levels. Sn concentrations were occasionally very high, with Sn associated with both PCIV and PCV: this is partly a product of the co-occurrence of Sn with geochemical signatures from different lithologies. Whilst it is clear that a Sn-associated signature exists in the dataset, it cannot define its origin and this signature becomes partially obscured by multiple lithologies. Nonetheless, integration with the microwear analysis has helped reveal the use histories of these artefacts.



A)

	Component 1	2	3	4	5
Mg	.379	-.501	.447	.154	.023
Al	.648	.629	-.037	.216	-.265
Si	-.821	-.069	-.135	-.313	.042
P	.595	.452	-.342	-.218	.252
K	-.250	.678	.657	.022	.030
Ca	.924	-.263	.147	-.063	.107
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W	-.128	.196	-.235	.903	.199
Pb	-.075	.292	.807	.226	.129

Extraction Method: Principal Component Analysis.
a. 5 components extracted.

Figure S2. *Principal Component Analysis of the surface readings from the original data. A) associations of the original elements to the new principal components; B) original elements shown against PCI and PCII; C) factor scores of PCI and PCII by artefact; D) factor scores of PCIV and PCV by artefact.*

MICROWEAR ANALYSIS

After the pXRF analysis, selected stone tools were investigated using microwear analysis: these are from Sennen PS07 (artefacts SF2, SF3, SF4, SF5, SF14, SF18, SF20, SF33); Lelant TR18 (artefact S1); and Truro (TEDC artefact S29). Microwear analysis is an analytical technique that identifies microscopic wear traces that develop on the surface of objects during manufacture, use, handling, but also through post-depositional processes (van Gijn, 2010, 2014; for a historical overview of the development of microwear analysis see van Gijn, 1990; Marreiros et al., 2015; Hamon et al., 2020). Microscopic observations were conducted at low (up to 100×) and high magnifications (100× and 200×) under a stereomicroscope (Leica M80) with an external, oblique light source and with a coaxial illumination unit (Leica M80 LED5000 CXI, magnifications up to 230×), and an incident light (metallographic) microscope (Leica DM1750M). Micrographs were taken with a Leica MC120HD digital camera and Z-stacks were created with the Helicon Focus software.

The recording and description of microwear features follows well-established methodologies and included grain edge rounding, levelling, grain extraction, the presence and distribution of striations and other linear features, micropolish features including morphology and development, microstriations, microfractures, and the presence of residues (Hamon, 2008; Dubreuil et al., 2015; Adams et al., 2009; Hayes et al., 2018). Based on experimental observations over the last twenty years, microwear analysis of ground stone tools have made it possible to establish that broad classes of worked materials (animal, plant, mineral) are associated with different microwear signatures including distinctive types of micropolish that develop on the surface of the tools during use (e.g. Dubreuil et al., 2015; Hamon, 2008; Hayes et al., 2018). More recently, experimental research has highlighted variations in microwear signatures that derive from the processing of different minerals (e.g. goethite, calcite, or copper ore; Caricola et al., 2020; Hamon et al., 2020). While more experiments are required to develop a better understanding of diagnostic microwear signatures associated with the processing of a wide range of minerals including cassiterite under different conditions (e.g. pounding, grinding), these studies bring to the fore how microwear analysis can improve current understanding of mineral processing activities in different archaeological contexts. The microwear patterns observed on our archaeological tools were interpreted in relation to the reference collection of experimentally-used tools housed at the Laboratory for Material Culture Studies at Leiden University, as well as published data (e.g. Caricola et al., 2020; Hamon et al., 2020). The reference collection comprises tools used for the processing of a wide range of plant, stone mineral (e.g. flint, basalt, amphibolite, clay, hematite) and animal materials.

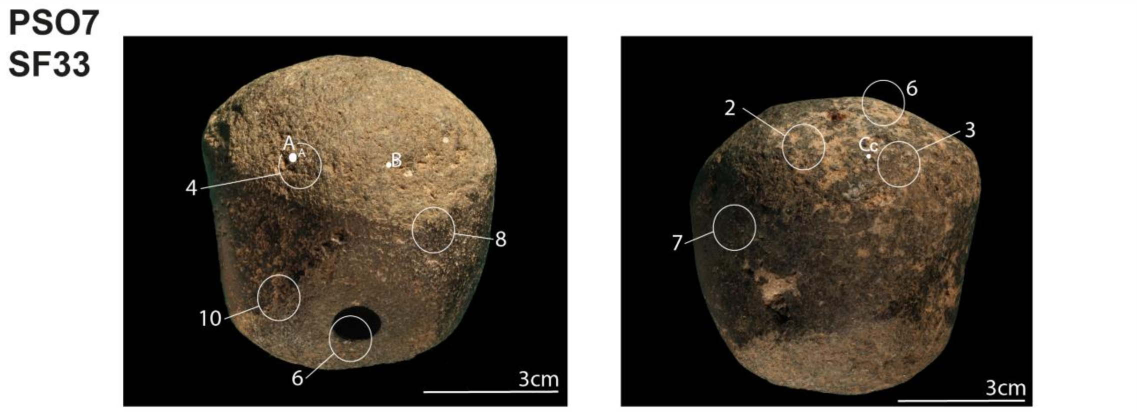
OBJECT BY OBJECT RESULTS OF THE MICROWEAR AND GEOCHEMICAL ANALYSES

The results presented here are for the artefacts that show strong evidence of use in processing cassiterite tin ore; consequently, Sennen PSO7 SF4, SF14, SF20, and Penzance TZH18 (all four artefacts from the latter site) are not discussed further here.

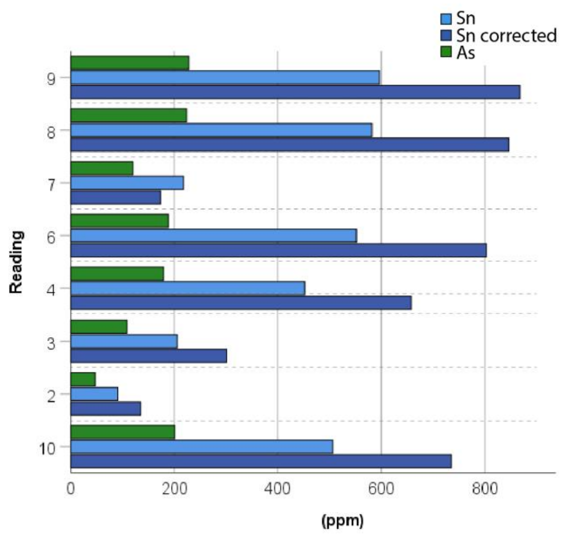
Sennen SF33 (greenstone pestle/pounder), context (101) (Figure S3)

SF33 is a complete cobble that shows intensive use as a pestle/pounder on two opposite ends. The crystal grains on End A exhibit step fractures and edge rounding (Figure S3 A). Two adjacent and distinct facets are visible on End B, one of which is more abraded, while the other facet has more developed pounding traces. Part of the naturally polished surface of the cobble is visible on the body of the cobble. At high magnifications, small patches of reflective micropolish with flat topography (Figure S3 B and C) are visible as developed on the higher elevation of the crystal grains. Wear traces are consistent with grinding/crushing actions of small-sized particles of a medium hard substance, possibly of mineral origin. Wear development including the creation of facets on the opposite ends suggests use with a rotational motion executed in a basin or hollowed surface.

SF33 has very high Sn and As concentrations on both working ends of the tool. This artefact was recorded as a greenstone, but it produced an anomalous geochemical signature, not fitting comfortably with either the granitic or greenstone artefacts. The origin of this signature is not clear, but the presence of elevated Sn on areas away from the working ends, e.g. reading 7, indicates that some Sn is derived from the tool's lithology. However, the extremely high Sn concentrations on the working ends of the tool (e.g. readings 4, 6, and 10) indicates some of this Sn is secondary, deriving from cassiterite residues; this is consistent with wear traces indicative of grinding/crushing materials likely to be mineral. A small core taken from SF33 showed Sn on both the interior and exterior of the core. Unfortunately, the interior of the core was broken at a point of mineral crystallization in the interior of the artefact, which displayed very high Sn concentrations (522ppm/800ppm) compared to the exterior (484ppm/701ppm). The material on the exterior of the core is not believed to be a crystalline deposit; however, this result proved ambiguous for the interpretation SF33's Sn concentrations. Whilst the pXRF analysis is ambiguous, the microwear traces confirm the use of this tool together with a basin for the pulverizing or pounding of hard mineral materials, interpreted as cassiterite.



Reading	As (ppm)	Original Sn / Corrected Sn (ppm)
2	47	91/135
3	109	206/301
4	179	452/658
6	189	552/803
7	120	218/174
8	224	582/846
9	228	597/868
10	201	506/735



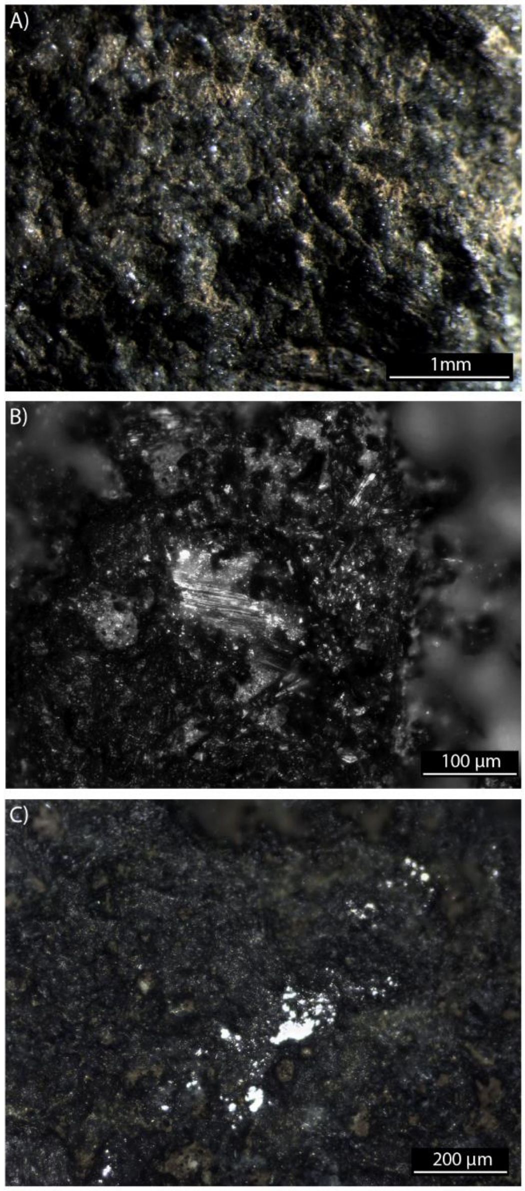


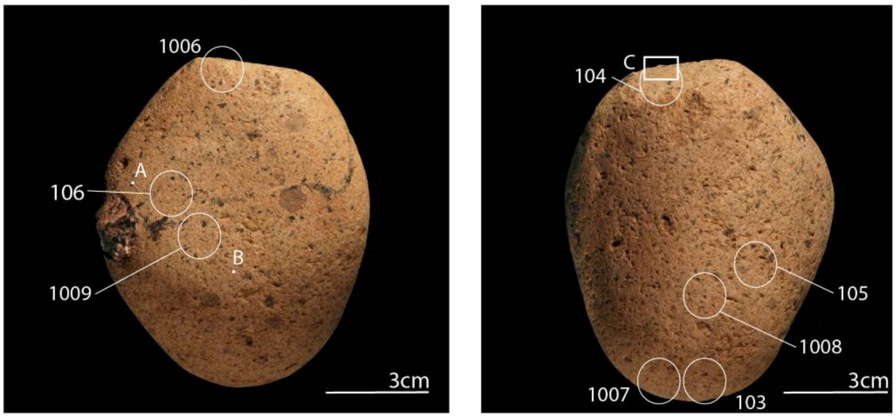
Figure S3. *Stone tool SF33: face A (top left) and face B (top right)]. Left: Sn readings and microwear traces. Right: A) grain edge rounding on End A; B) and C) small patches of flat, reflective micropolish with flat topography.*

Sennen SF18 (granite grinding/pounding tool), context (89) (Figure S4)

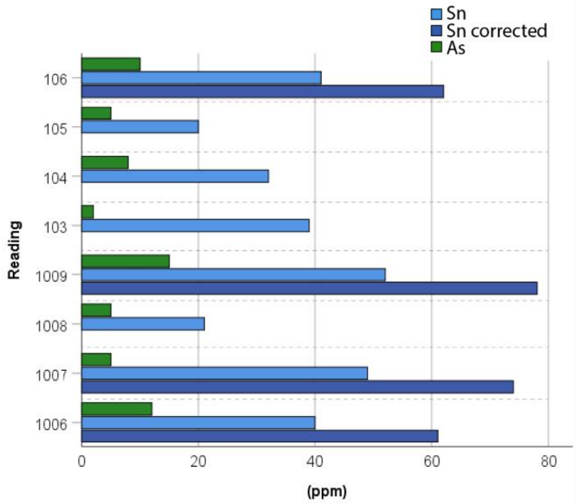
SF18 is a complete grinding/pounding tool that has three main zones of use. On face A, the flattened area of the tool has a rather sinuous topography with grains showing levelling on the higher elevations and rounding at their edges (Figure S4 A). In places, the levelling is associated with parallel striations and grain extraction. The surface also exhibits light percussive traces suggesting the dual use of the tool for grinding and pounding. At high magnifications, microfractures commonly occur across the flattened surface along with a reflective micropolish of flat topography with (Figure S4 B) or without striations and pitted appearance. The micropolish develops in closely distributed but not connecting patches on the higher asperities of the microtopography and the highest part of the interstices. Both narrow ends of the tool display a combination of abrasive and pounding wear traces, although wear traces are more developed on End A. The crystal grains show impact fractures with a pointed morphology and crushing on the higher elevation of the grains, and occasionally edge rounding and micropolish (Figure S4 C). The combination of microwear traces is consistent with the use of the tool for grinding and pounding or pulverizing semi-hard material of mineral origin.

SF18 had generally low Sn concentrations, with uncorrected >40ppm values detected four times (readings 1006, 1007, 1009, and 106), although Sn is recorded in all eight readings. Slightly higher Sn concentrations are recorded on the ends of the tool, consistent with the microwear results for grinding/pulverizing activities, with readings 1009 and 106 taken on the flattened use-surface of the tool, whilst reading 1006 was taken at the narrow end of the tool, which had the more developed wear traces. Given that this tool is of granitic origin, it is likely that some of these Sn readings derive from the lithology and are within published ranges for Cornish granite (*c*. <50ppm) (Smith, 1995; Simons et al., 2017), although the slight elevations in Sn on the working faces and ends are interpreted as potentially partially derived from its use.

PSO7
SF18



Reading	As (ppm)	Original Sn / corrected Sn (ppm)
103	2	39
104	8	32
105	5	20
106	10	41/62
1006	12	40/61
1007	5	49/74
1008	5	21
1009	15	52/78



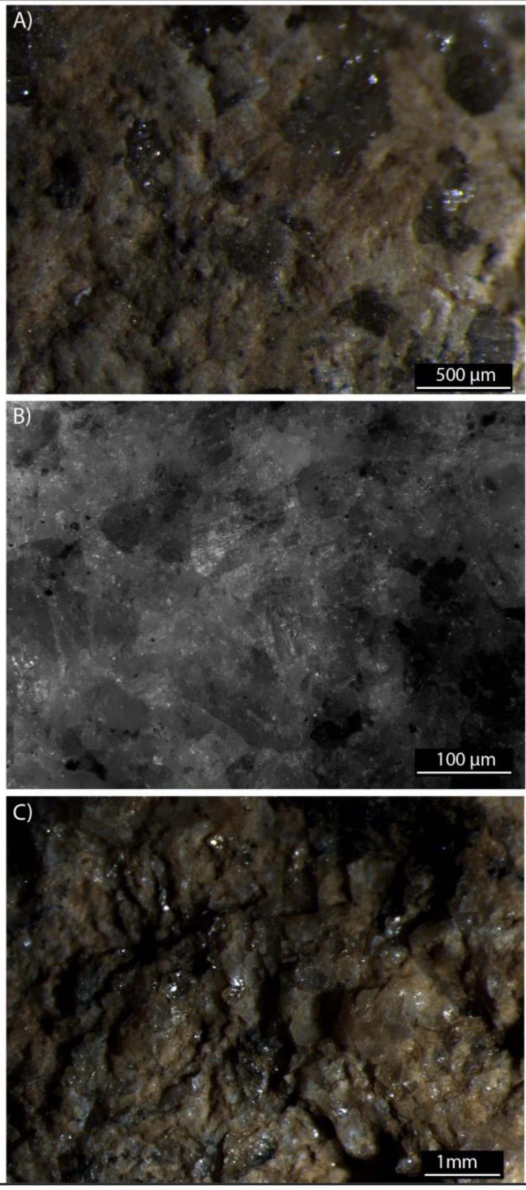


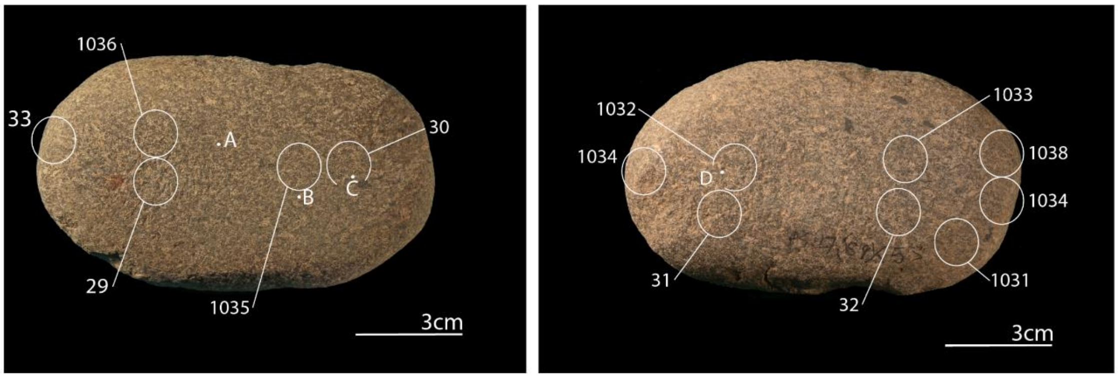
Figure S4. *Stone tool SF18: face A (top left) and face B (top right)]. Left: Sn readings and microwear traces. Right: A) levelling of topography; B) reflective micropolish of flat topography; C) crystal grains showing impact fractures and occasional edge rounding on End A.*

Sennen SF5 (greenstone beach cobble grinding/pounding tool), context (89) (Figure S5)

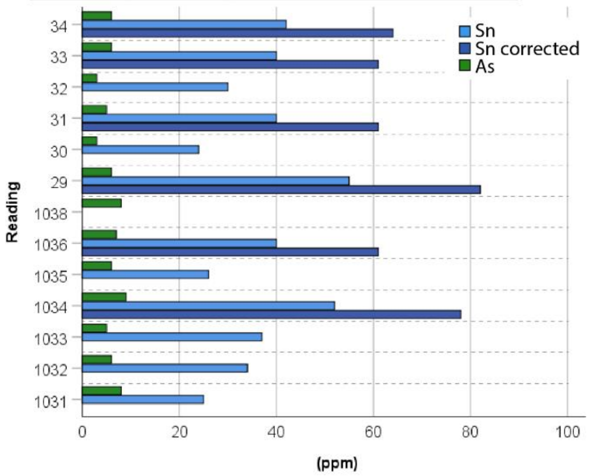
SF5 is a complete grinding/pounding tool that exhibits different zones of use, and intentionally produced notches, possibly used as finger grips, are visible on the margins of the tool. Both broad surfaces of the tool exhibit levelling of the higher elevations of the surface topography with the resulting plateaus showing rounding at their edges. In places, the levelling is associated with deep, wide, parallel striations and grain extraction (Figure S5 A). The association of light pounding traces with abrasive wear indicates the dual use of the tool for crushing and grinding, while the presence of deep striations suggests an intermediate substance of abrasive nature. At high magnifications, a highly reflective, striated micropolish of flat topography that forms elongated patches with different directionality is visible across the surfaces (Figure S5 B, C, and D). This is consistent with contact with a semi-hard material of mineral origin. Both ends of the tool exhibit grain extraction and occasional grain edge rounding consistent with pounding actions. Wear patterns suggest that the tool was used to reduce and pulverize larger fragments of semi-hard mineral matter into smaller, finer particles.

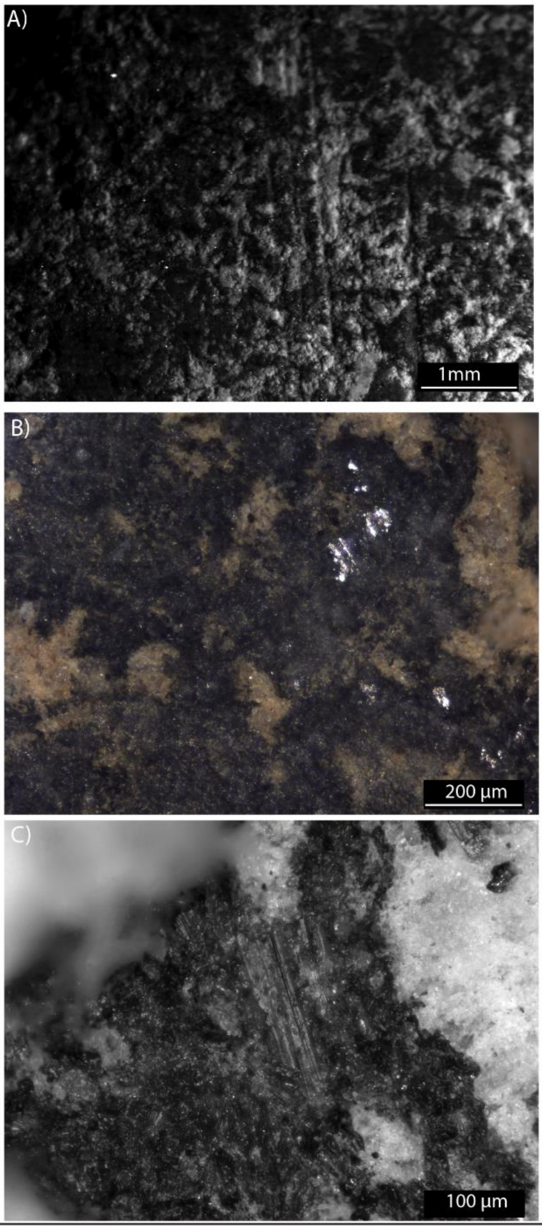
SF5 had uncorrected Sn >40ppm detected in six readings, although some measurement of Sn was present in every reading except reading 1038. The tool has small elevations on its ends (e.g. reading 1034) and its broad surfaces, and this correlates with the observed wear traces. The Sn or As concentrations are not unequivocally high but, given the greenstone lithology of this artefact, it is probable that some of the Sn concentrations derive from surface residues. The microwear results, alongside low-level Sn enhancements on the working ends provides a compelling case for the processing of a hard mineral substance, most likely to be cassiterite.

PSO7 SF5



Reading	As (ppm)	Original Sn / corrected Sn (ppm)
1031	8	25
1032	6	34
1033	5	37
1034	9	52/78
1035	6	26
1036	7	40/61
1038	8	-
29	6	55/82
30	3	23
31	5	40/61
32	3	30
33	6	40/61
34	6	42/64





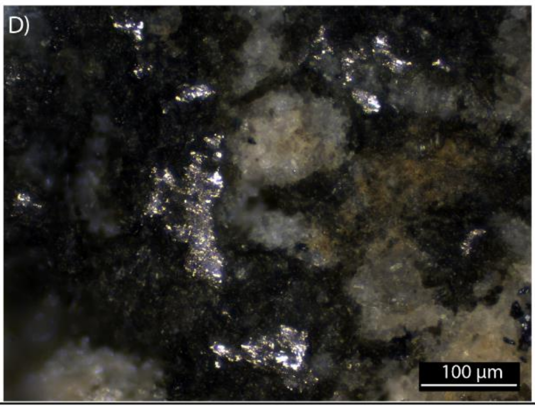


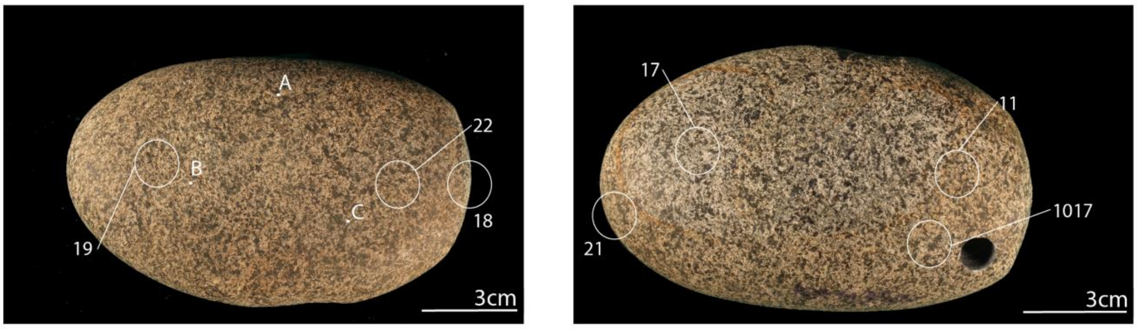
Figure S5. *Stone tool SF5: face A (top left) and face B (top right). Centre-left: Sn readings and microwear traces. Right: A) linear features in the form of striations; B), C), and D) (bottom left): highly reflective, striated micropolish of flat topography.*

Sennen SF3 (greenstone beach cobble grinding/pounding tool), context (89) (Figure S6)

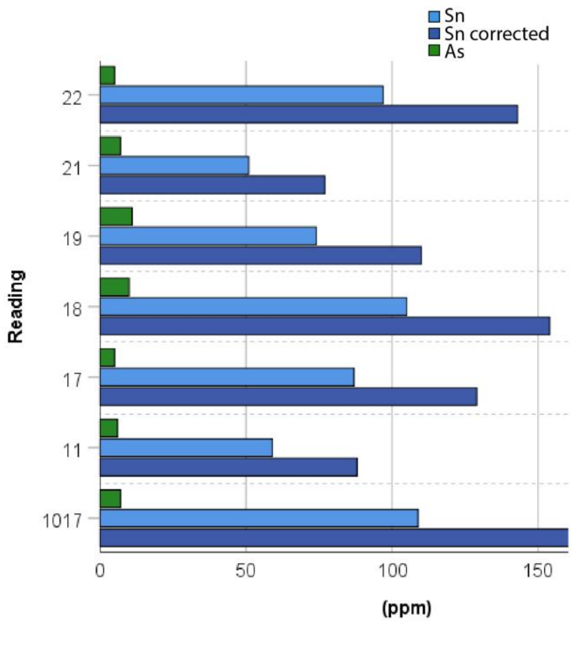
SF3 is a complete grinding/pounding tool that exhibits multiple zones of use, and an intentionally produced wide notch, possibly created to improve handling (finger grip) is visible on one of the margins. One of the broad surfaces (face A) of the tool is flat in section and exhibits levelling of the higher elevations of the surface topography with the resulting plateaus showing rounding at their edges. In places, the levelling is associated with wide, parallel striations along with grain extraction (Figure S6 A and B). The association of light pounding traces with abrasive wear indicates the dual use of the tool for crushing and grinding. At high magnifications, a highly reflective, striated micropolish of flat topography, that forms elongated patches with directionality diagonal to the long axis of the tool and affects the higher microtopography, is visible across the tool surface (Figure S6 C). Overall, the observed wear traces are consistent with contact with a semi-hard material of mineral origin. The opposite face of the tool (face B) is convex and exhibits occasional levelling (though not as developed as on face A), and grain edge rounding accompanied by striations and light percussive traces. One narrow end exhibits crystal grains with step fractures or pointed morphology, accompanied by grain extraction and occasional grain edge rounding. Less well developed percussive traces are visible on the opposite narrow end of the tool. The microwear traces and wear development suggest that the tool was used as a tool to reduce and pulverize larger fragments of semi-hard mineral matter into smaller, finer particles.

SF3 has moderate to high Sn concentrations. It is notable that one of the highest Sn concentrations (reading 18 109/152ppm) was on the narrow end where more developed percussive wear traces were observed. The generally lower Sn concentrations are likely to be at least partially caused by some natural Sn found within Cornish granite (*c*. <50ppm) (Smith, 1995; Simons et al., 2017). The small core taken from SF3 could not detect Sn residues on the interior or exterior of the core, increasing our confidence that the localized detection of Sn on the surface is derived at least partly from residues associated with the use of the artefact.

PSO7 SF3



Reading	As (ppm)	Original Sn / Corrected Sn (ppm)
11	6	59/88
17	5	87/129
18	10	105/154
19	11	74/110
21	7	51/77
22	5	97/143
1017	7	109/161



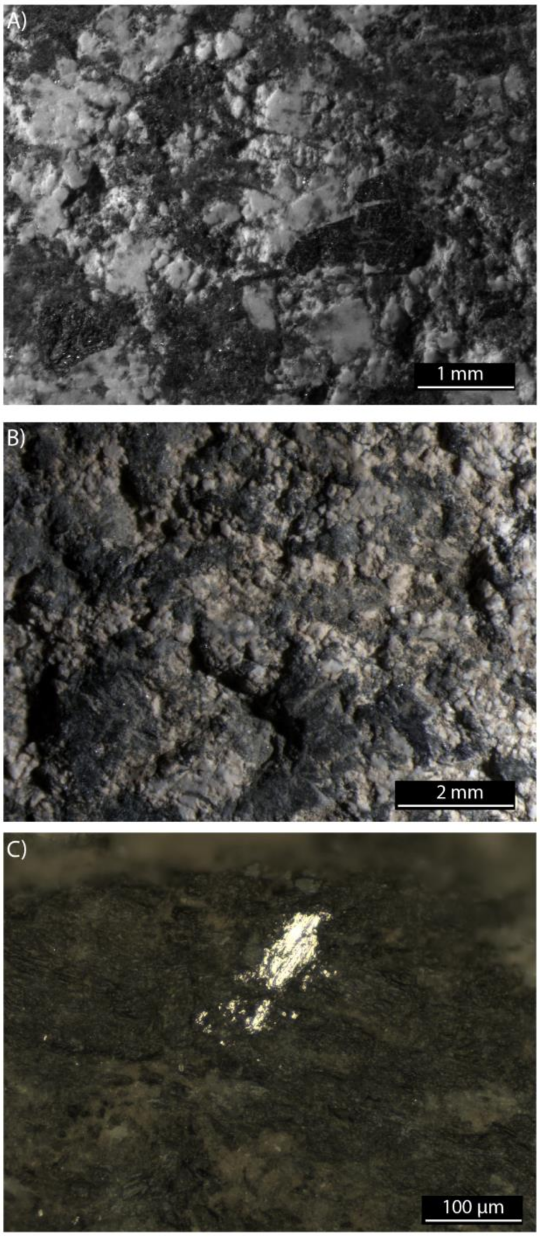


Figure S6. *Stone tool SF3: face A (top left) and face B (top right). Left: Sn readings and microwear traces. Right: A) levelling of topography; B) grain extraction; C) a highly reflective, striated micropolish of flat topography.*

Sennen SF2 (quartzite, percussive tool), context (89) (Figure S7)

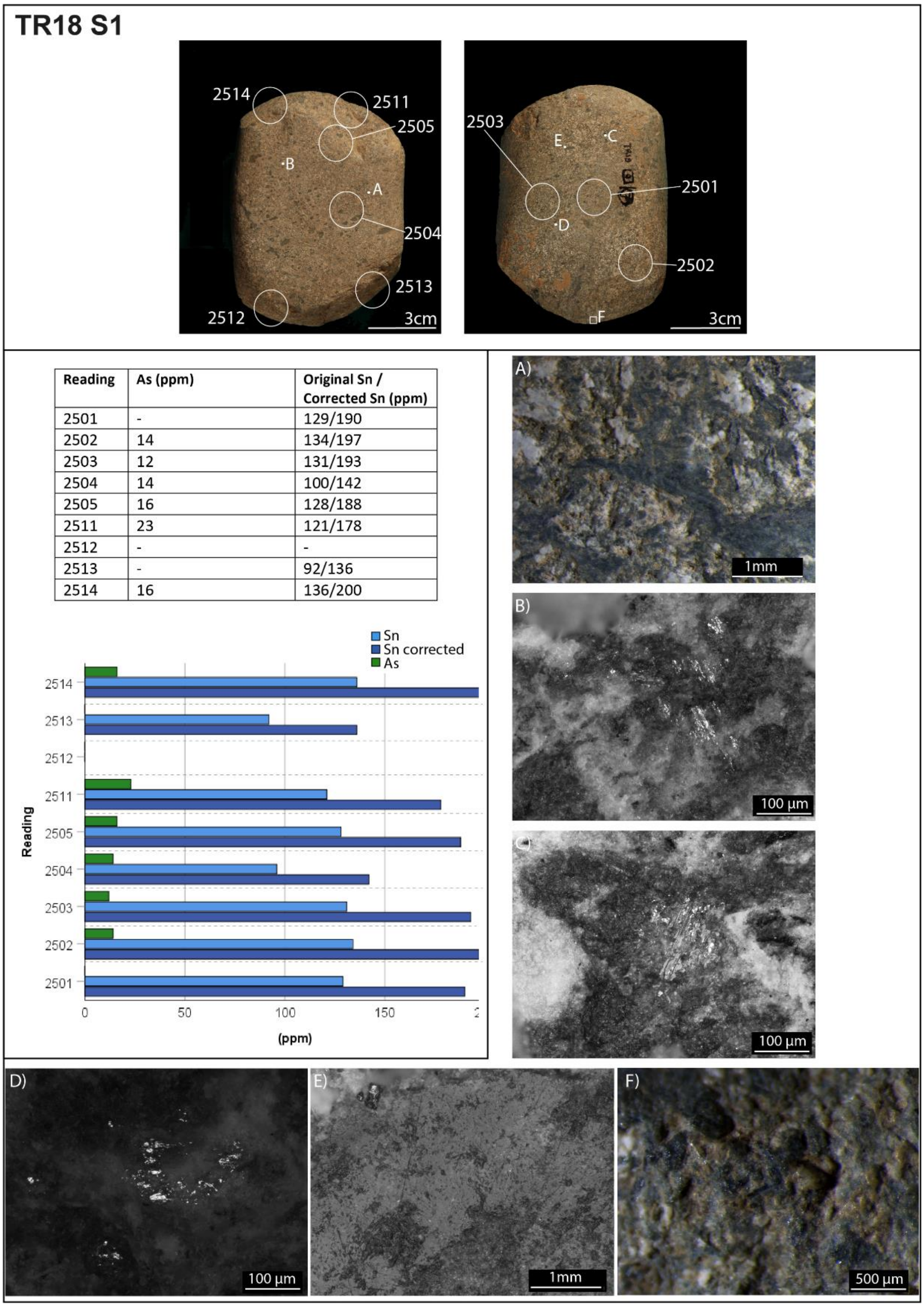
SF2 is a complete quartzite cobble that has a series of intentionally hammered/pecked hollows on the body and the margins to facilitate hafting. Similar implements have been reported from other prehistoric sites in Britain, Ireland, and continental Europe and have been associated with ore extraction and mineral processing activities (e.g. O'Brien, 2004; Delgado Raack & Risch, 2008; Caricola et al., 2020; Hamon et al., 2020). In the case of SF2, no wear traces associated with hafting were observed, which would suggest that after the hollows were made the tool saw no or very limited use as a hafted implement. Both ends of the tool were used for percussive actions. Wear traces include grain extraction (Figure S7 A) and grain fractures that have a pointed morphology and step fractures on the highest elevation of the crystal grains alongside occasional shearing (Figure S7 B). At high magnifications, wear traces include patches of a micropolish with flat topography, which affect the higher microtopography, and microfractures. On End B, pounding has resulted in the creation of two adjacent facets. Given the location and microwear signatures indicative of use against a medium hard material of mineral origin, this implement possibly functioned as a tool for breaking up larger nodules into smaller fragments. However, no Sn or As was detected on SF2; therefore, this tool can only be interpreted as having been used against a hard stone or mineral material.

Figure S7. *Stone tool SF2: face A and margin (top). Below: A) overview of surface topography and grain extraction; B) grain microfractures.*

TR18 S1, Lelant pit [6] (grinding/percussive tool) (Figure S8)

S1 is a greenstone cobble that is sub-rectangular when viewed in plan. The broad faces of the tool exhibit levelling of the topography accompanied by long striations with loose distribution and low density, grain removals and fractures (Figure S8 A). At high magnifications, elongated (not connected) patches of a highly reflective, striated micropolish of flat topography are visible on the higher elevations of the microtopography (Figure S8 B and C). The patches of micropolish have a directionality diagonal to the long axis of the tool. The micropolish, which is consistent with contact with a semi-hard material of mineral origin, looks more reflective where residue is still present. Micropolish with similar features is present on face B (Figure S8 D), which also exhibits patches of micropolish with flat topography and smooth texture (or in places a combination of smooth and rough-textured micropolish), with multi-directional striations that develop on the higher elevations of the microtopography (Figure S8 E). The patches are closely distributed but not linked. This well-developed micropolish is consistent with hard mineral contact, more specifically stone on stone contact that has resulted in the intentional polishing of the tool surface. Both narrow ends show grain edge rounding (Figure S8 F) and, in places, the grain crystals have a greasy appearance (occasional microfractures of pointed morphology and micropolish). Variation in the wear traces encountered on the different faces of the tool suggest it was used for pounding and grinding mineral material, but also possibly for smoothing and shaping metallic objects.

The Sn concentrations on this tool are again high, with eight uncorrected readings above 40ppm present, including five above 100ppm, with arsenic (As) also moderately present in five readings. The degree of Sn is high on the working surfaces, for example readings 2502, 2503, and 2505, although there is no notable difference in the Sn concentrations between the two faces. The suggestion that one surface was used for shaping/smoothing metallic objects, as indicated by the microwear, is intriguing, although the geochemistry does not show variability between the two faces and no Cu was detected on the object.



Reading	As (ppm)	Original Sn / Corrected Sn (ppm)
2501	-	129/190
2502	14	134/197
2503	12	131/193
2504	14	100/142
2505	16	128/188
2511	23	121/178
2512	-	-
2513	-	92/136
2514	16	136/200

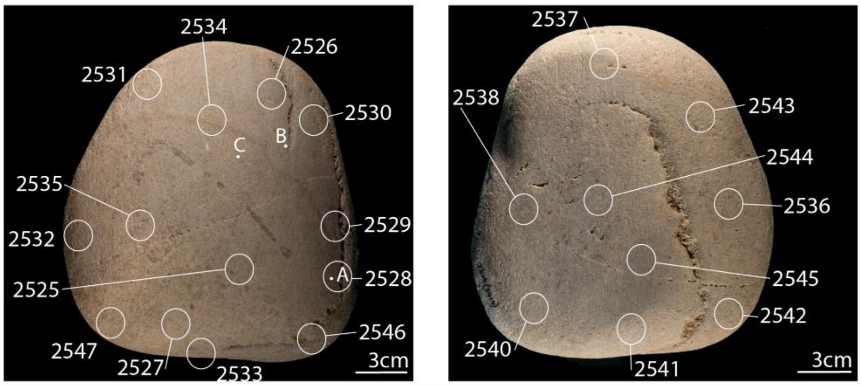
Figure S8*. Stone tool TR18 S1: face A (top left) and face B (top right). Centre-left: Sn readings and microwear traces. Right and bottom row: A) levelling of the topography accompanied by long striations with loose distribution and low density; B), C), and D) highly reflective, striated micropolish of flat topography; E) patches of micropolish with flat topography and a combination of smooth/rough-textured micropolish with multi-directional striations; F) grain edge rounding on End B.*

TEDC-S29 (sandstone, lower grinding tool), pit 3414 (Figure S9)

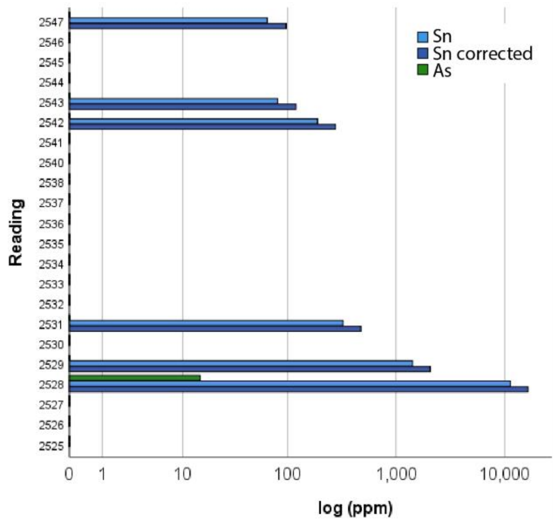
S29 is a large beach cobble of Gramscatho type sandstone. One of the broad faces of the tool (face A) displays more developed wear traces that include levelling of the topography and creation of plateaus across the whole surface of the tool, with more intense levelling observed along the margin and near the area where natural faults are present in the cobble (Figure S9 A). The levelling is accompanied by longitudinal striations, which are directionality parallel to the long axis of the tool, while limited grain removals and occasional grain fractures are present. At high magnifications, small patches of reflective micropolish with pitted appearance and flat topography and sharp boundaries show a localized distribution (Figure S9 B and C). The micropolish develops on the higher elevations of the microtopography and in places it follows the grain topography but does not affect the interstices. A silvery-metallic residue that forms intermittent streaks is present on the surface of the tool and is found in association with areas that also exhibit levelling of the topography. The wear traces are consistent with the use of the tool as a lower (stable) grinding tool for grinding small particles of a medium-hard contact material into finer particles.

On this tool, the Sn concentrations were localized and extremely high, with six uncorrected readings above 40ppm (readings 2528, 2529, 2531, 2542, 2543, and 2547), but conversely Sn was not detected in a further sixteen readings. This distribution fits well with the localized distribution of the micropolish on the surface. Notably, readings 2528 and 2529, recorded close to the small fracture on the tool surface, gave very high Sn concentrations. However, readings 2531, 2542, 2543, and 2547 on the use faces are all in the range of high tens to low hundreds, more consistent with the readings on the use faces of the other tools. We noted that As only shows elevation in reading 2528, associated with the very high Sn concentration. Since this tool is made of Gramscatho sandstone, it is impossible for the detected Sn to have derived from the tool’s lithology (Shail & Floyd, 1988); it can only be explained as a surface residue. Read in combination, the microwear and pXRF data suggest that this tool was used as a stable grinding surface for the processing of cassiterite.

TEDC S29



Reading	As (ppm)	Original Sn / Corrected Sn (ppm)
2525	-	-
2526	-	-
2527	-	-
2528	15	11315/16401
2529	-	1427/2071
2530	-	-
2531	-	327/477
2532	-	-
2533	-	-
2534	-	-
2535	-	-
2536	-	-
2537	-	-
2538	-	-
2540	-	-
2541	-	-
2542	-	190/278
2543	-	81/120
2544	-	-
2545	-	-
2546	-	-
2547	-	65/97



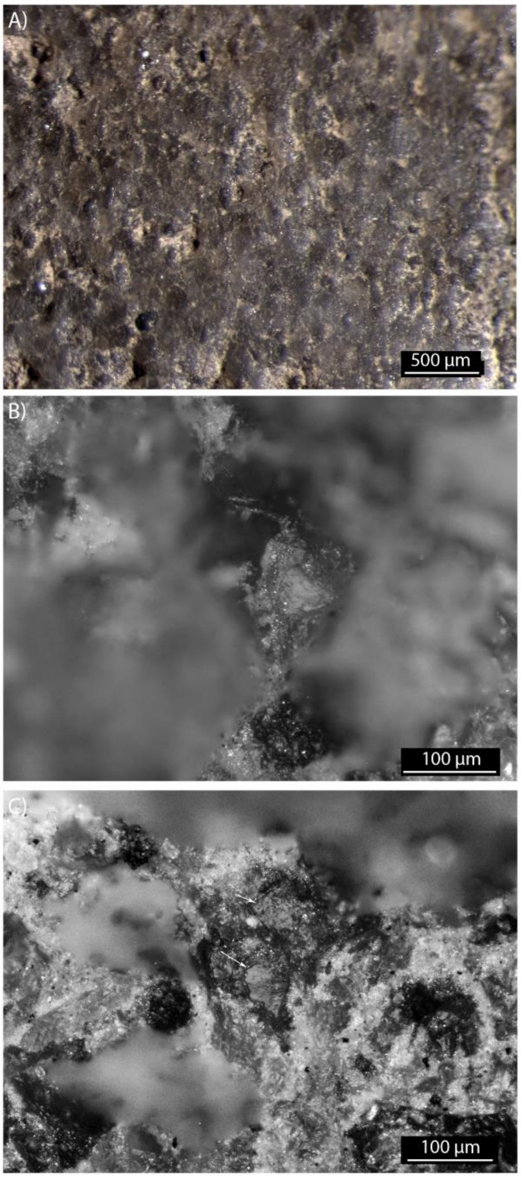


Figure S9. *Stone tool TEDC S29: face A (top left) and face B (top right). Left: Sn readings and microwear traces. Right: A) levelling of the surface topography; B) and C) localized distribution of reflective micropolish with pitted appearance and flat topography and sharp boundaries.*

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