Optimal versus minimal preservation: two case studies of Bronze Age ore processing sites

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ABSTRACT: Ore processing is a fundamental step in copper metal production. Despite our burgeoning knowledge of Bronze Age copper mining in the British Isles, unambiguous evidence for this activity during the 2nd millennium BC remains scarce here. In contrast, recent excavations on the continent have uncovered well-preserved, securely-dated evidence for ore processing, particularly the use of gravity separation in water, during the Bronze Age at sites such as Troiboden in the Mitterberg, Austria. This paper considers the implications of this evidence for our understanding of Bronze Age ore processing within British contexts, particularly on the Great Orme headland. At the site of Ffynnon Rhufeinig, located close to a water source near extensive prehistoric mine workings, beneficiated mining waste has been excavated and radiocarbon dated to the Early Bronze Age. We argue that, to avoid destruction, such sites deserve better recognition and conservation as part of complex, multi-phase prehistoric mining landscapes.

Introduction

Beneficiation is the next stage after mining in the production of copper metal. Its aim is to separate the desired ore minerals from the barren host rock, or gangue, to produce a concentrate suitable for smelting. In prehistory, mechanical techniques, such as coarse and fine crushing and grinding using stone tools, were used to reduce the fragments of mined ore to a smaller particle size. A series of filtering steps, exploiting differences in relative colour, lustre, hardness and density, were then utilised to separate the desired copper minerals from the unwanted gangue by hand sorting and picking or gravity separation in water.

The study of beneficiation is important for our understanding of the production of copper metal from ore in prehistory. It not only increased the yield of metal produced for a given input of ore, but it influenced the practical choices made at the smelting stage, such as the amount and type of fuel required. It would also have reduced the weight of ore transported from the mine to the smelting site.

The focus of this paper is gravity separation in water, also referred to as wet ore processing or ore washing, during the British and European Bronze Age, a period spanning the late 3rd to early 1st millennium BC. The early-mining researcher Billy O'Brien (2015, 222) has recently pointed out that wet ore processing may have been an option for many of the copper ore deposits mined in prehistory, if they were close to a suitable water source, given the difference in density between mineral and gangue. The specific gravity of the copper ores malachite, chalcopyrite and tennantite, for example, are 3.97, 4.20 and 4.85 respectively, compared to the lower value of 2.60, 2.65 and 2.85 for the typical host rocks feldspar, quartz and dolomite (Williams 2018). The denser copper minerals hence sink in water, while the lighter gangue material is suspended and can be floated away or removed by hand.

However, despite the discovery in the last 30 years of numerous Bronze Age mines in Britain and Ireland (*eg* O'Brien 2014; 2015; Timberlake 2017), none, with the exception of the Great Orme mine in north Wales, discussed below, have yet produced positive evidence

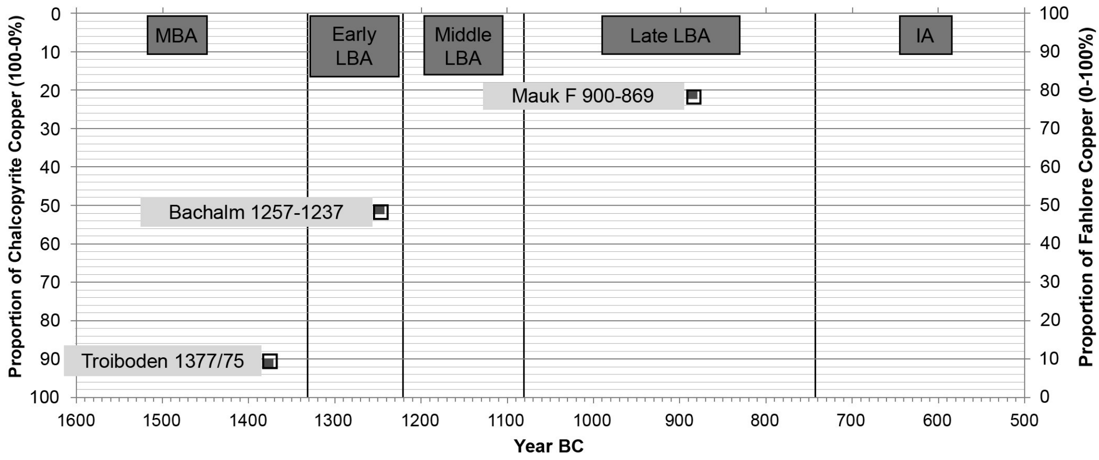


Figure 2: Dendro-dates and copper ore types from the ore-washing sites of Troiboden, Bachalm and Mauk F (after Nicolussi et al 2015, 244, fig 7).

for associated ore washing. Wooden launders (lengths of halved and hollowed logs), excavated from the Early Bronze Age copper workings at Copa Hill, Cwmystwyth, mid Wales, may have had a dual function for both ore washing and drainage, although the latter is considered to have been their primary purpose (Timberlake 2003, 69–70).

This contrasts with the situation in mainland Europe, where securely dated evidence for wet ore processing from the late 3rd millennium BC onwards is now known from numerous sites, including Roque-Fenestre in the Cabrières region of southern France (Espérou 1993; Ambert 1995), Acqua Fredda in the Trento area of northern Italy (Perini 1992; Cierny *et al* 2004; Silvestestri *et al* 2015) and, in particular, in Austria in the Eastern Alps.

In this paper, the evidence for ore washing during the Bronze Age from two distinct case-study areas will be briefly presented: firstly, from the Mitterberg, Kitzbühel and Schwaz-Brixlegg mining districts of Austria, and secondly at Ffynnon Rhufeinig on the Great Orme headland, in Wales, UK. Using these data, the implications of the Austrian evidence for research into Bronze Age ore washing on the Great Orme will be assessed.

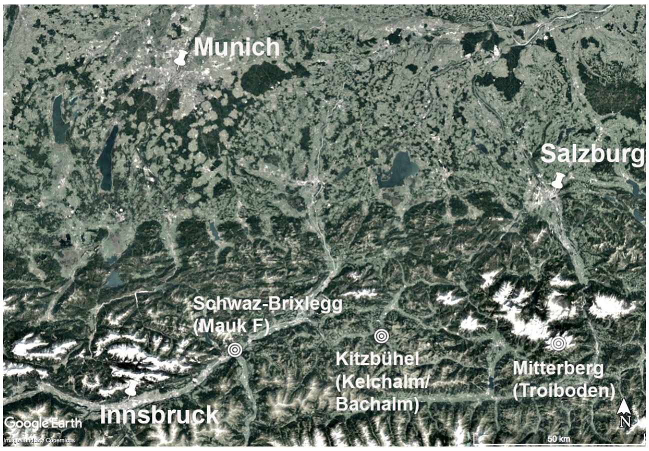


Figure 1: Location of the Mitterberg, Kitzbühel and Schwaz-Brixlegg mining districts in the Austrian Eastern Alps, showing the Bronze Age ore-washing sites of Troiboden, Kelchalm/ Bachalm and Mauk F. Image width 180km.

Case-study 1: Bronze Age ore washing in the Eastern Alps

In the last two decades there has been detailed archaeological excavation of prehistoric wet-processing landscapes in the Eastern Alps of Austria. Three of these will be considered here (their approximate geographic location is shown in Figure 1**;** the relative chronology and ore types processed are shown in Figure 2).

The first lies in the Mitterberg area, near Salzburg. Excavations at the well-preserved subterranean Bronze Age copper mine at the Mitterberg itself have shown impressive and advanced mining and engineering techniques. These have now been complemented by recent excavations of an ore-processing landscape at adjacent Troiboden, a hypertrophic moor in the Sulzbachmoos. LiDAR survey (Stöllner 2015, 180, fig 12) and an extensive coring programme identified a substantial length of open-cast mining (*Pingen*) exploiting rich chalcopyrite ores within the predominately quartz-dolomite host rock, accompanied by spoil heaps (*Halden*). Running alongside these are areas with several ore-processing sites (*Aufbereitung*). Activities at these sites have been dated by dendrochronology to the 14th and 13th centuries BC (Middle Bronze Age) (Stöllner *et al* 2010; Nicolussi *et al* 2015, 245; Pernicka *et al* 2016, 22).

The second ore-washing landscape, located at Bachalm in the Kitzbühel mining district, is situated adjacent to the neighbouring production site of Kelchalm, on a sloping plateau near a stream at an altitude of approximately 1700m. Bachalm is well-known for having been first excavated in the mid 20th century by Preuschen and Pittioni, who were able almost to reconstruct the entire sequence of chalcopyrite ore washing there (*eg* Preuschen and Pittioni 1954). Wooden finds from new excavations have been dated by dendrochronology to 1257–1237 BC, *ie* the earlier Late Bronze Age. Mining in the Kitzbühel region appears to have been at its height during this period, although no mine workings have been located at Bachalm due to the fragmentary nature of the metamorphosed sedimentary host rock (Klaunzer 2008; Nicolussi *et al* 2015; Koch Waldner 2017).

The final Austrian wet ore-processing site is Mauk F, located on the now almost drained Schwarzenbergmoos mire in the Schwaz-Brixlegg mining area. Mauk F is one of five prehistoric sites in the small high-altitude Mauken Valley, which together have provided archaeological evidence for every stage in the sequence of copper production from mining to smelting during the later Bronze Age and early Iron Age. In contrast to Troiboden and Bachalm, the ores being exploited by the Mauken miners were mainly copper-sulphide fahlores of the antimony- and arsenic-rich tennantite-tetrahedrite series in dolomitic rock. Dating of excavated wood by dendrochronology indicates that Mauk F was in use intermittently over a period of only about 30 years during the later Bronze Age, from 900 to 869 BC (Breitenlechner *et al* 2013; Goldenberg 2015; Nicolussi *et al* 2015).

Figure 3: Wooden sluice boxes from Troiboden during excavation. A) Sluice box 2, approx 1.4 x 1.4m, dated by dendrochronology to 1377/76 BC. B) Sluice box 3; the upper box dates to 1290–1276/75 BC (dating after Pichler et al 2018).

Although these three sites are not contemporary – and there are other dissimilarities, such as the type of ore being processed (Fig 2) – they share a number of common features. These include the occurrence of deposits of characteristic waste from ore washing, which typically comprise complex interplays of sediments ranging from coarse-grained granular to fine-grained sandy-silty layers. At Troiboden, massive buried heaps of sedimentary material produced by both wet and dry ore processing extend for 200m (Stöllner *et al* 2010). At Bachalm, the waste heaps (*Scheidehalden*) are still prominent features in the landscape. Recent excavation of one example uncovered sandy sediments from ore washing (*Waschsand*) (Klaunzer *et al* 2009; Koch Waldner and Klaunzer 2015; Koch Waldner 2017).

Washing-waste tips 8m wide by 12m long and up to 0.8m thick have also been recently excavated at Mauk F. These comprised layers of yellowish-white crushed dolomite with traces of malachite. Light green-turquoise deposits were also uncovered. On the basis of their fine particle size, these are interpreted as the overflow material from the ore-washing process (*Waschabgänge*). White crushed material found all over the excavated area represented the prehistoric working surface (Klaunzer *et al* 2008; Nicolussi *et al* 2010).

The richness and variety of the wooden finds from all three sites is striking. At Mauk F, more than 100 wooden items, including posts, boards, and worked logs, were excavated. At Bachalm, the range of wooden artefacts included buckets, shovels, roof shingles, cooking implements, nails and posts. Associated with the ore-washing-waste tips at each site were features for wet processing, specifically wooden sluice boxes (*Erzwaschkästen*; Fig 3) and settling troughs (*Sichertröge*; Fig 4). These are particularly strong indicators of ore washing. At each site, these wooden features were accompanied by stone implements for the crushing and grinding of ore. Unusual wooden artefacts interpreted as knives were also found at all three sites (Breitenlechner *et al* 2013; Goldenberg 2015, 157, fig 8; Koch Waldner and Klaunzer 2015, 168, fig 5; Koch Waldner 2017).

The excellent preservation of wood in the waterlogged conditions at Troiboden, Bachalm and Mauk F allows the ore-washing process to be reconstructed in detail (Stöllner *et al* 2010; Stöllner 2015). It is clear that the Bronze Age workers invested a high degree of planning, organisation and technological know-how into ore washing. Taking Troiboden as an example, in the summer of 1376 BC and the following autumn, local spruce and larch trees were felled. The area was then drained and gritted before a working platform of branches, wood chips and bark was laid down. A wooden sluice box was carefully designed and built from grooved planks and anchored by posts into the centre of the platform. A transverse timber board was fitted into two grooved slots, dividing the box into two compartments. Holes were pierced into opposing sides of the box at different heights for water inlet and outflow. Water run-off from the mire was then channelled into the sluice box. Heavy use-wear around the water inlet indicates that the water flow could be – and indeed had been – regulated. The mined ore was crushed and possibly also ground before being added to the sluice box and agitated in the standing water. This caused the denser ore fraction to settle in the upper part of the box. The less dense gangue was floated over the central partition, perhaps with the aid of the wooden knives.

Both large and small cup-marked stones were found associated with the sluice box. These indicate that the ore fraction from the sluice box was crushed again in situ before further concentration took place (Stöllner *et al* 2010; Stöllner 2015). The remains of a total of 15 sluice boxes have been excavated at Troiboden, pointing to large-scale wet ore processing at this site (Stöllner, pers comm).

Figure 4: Settling trough from Mauk F during excavation, dated by dendrochronology to 892 BC (Late Bronze Age). Scale bar 1m.

Figure 5: Replica settling trough in use (700mm x 300mm x 130mm).

At Mauk F, the remains of half a settling trough with wooden protrusions on the side have been found preserved (Klaunzer *et al* 2008). Daniel Modl at the University of Graz has demonstrated how this artefact may have been used. He suspended a replica trough from a branch and filled it with water and crushed ore with a particle size of <5mm (Fig 5). He found that by pulling to and fro and gently lifting and lowering the back of the trough and then carefully tilting it to let the water run out, the coarser ore particles, having accumulated at the top, could be skimmed off cleanly using a wooden knife or spatula. The gangue was left behind as a fine sludge in the base of the trough (Modl 2011; 2015). It is clear that further replication experiments investigating the separation behaviour of coarse compared to fine ore particle sizes are needed. However, Modl's research found that using a settling trough is an effective method of separating fahlore ore from the Mauken Valley from its carbonate matrix after crushing to a particle size smaller than 5mm (Modl 2011, 124, 130). His experiments also demonstrated the efficacy of this method for concentrating Mitterberg ore, although the excavators found no archaeological evidence to support the use of the settling trough technique at Troiboden (Stöllner, pers comm).

X-ray fluorescence analysis of the washing-waste heaps at Troiboden found they contained only 0.1–0.5% copper, with an average copper loss (the amount of residual copper as a proportion of the total mass of the waste heaps) of 0.5% compared to previous estimates of 1.15–10% (Rashidian 2016). Such very thorough separation could have been achieved using the sluice box as part of a complex, multi-stage sequence of repeated crushing, grinding, sieving, washing and sorting. From the field and mineral evidence, the excavators concluded that most of the rich chalcopyrite ores from the Mitterberg were probably extracted in sufficiently high concentrations to be reduced by smelting without additional ore processing and so would have been transported directly from the mine to the smelting site. Only the low-grade ore was concentrated by wet ore processing using a sluice box to produce a standardised smelting charge (Stöllner, pers comm).

The Bronze Age workers of the Austrian Eastern Alps appear to have used the very simple technology of the sluice box and settling trough selectively. By exploiting effectively the density of the mined ore they achieved a greater degree of enrichment of certain copper ores – increasing the yield of copper metal when smelted – than would have been possible without these wet-processing methods.

Case-study 2: Bronze Age ore washing on the Great Orme

The second case-study area, the site of Ffynnon Rhufeinig or the *Roman Well* (NGR SH 7660 8390), also known as Ffynnon Llety Madoc, is a natural spring on the Great Orme headland, on the coast of north Wales (Wager 1996; 1997). It is less than a kilometre from the well-known Great Orme mine (Fig 6), where mainly secondary malachite-goethite deposits within rotted dolomitic limestone were extracted during the Bronze Age on a scale unprecedented elsewhere in Britain and Ireland. The most active phase of prehistoric mining on the headland occurred during the Middle Bronze Age, between approximately 1500 and 1300 cal BC (Dutton *et al* 1994; Lewis 1996; Wager 2002; Williams 2017; Timberlake and Marshall 2018).

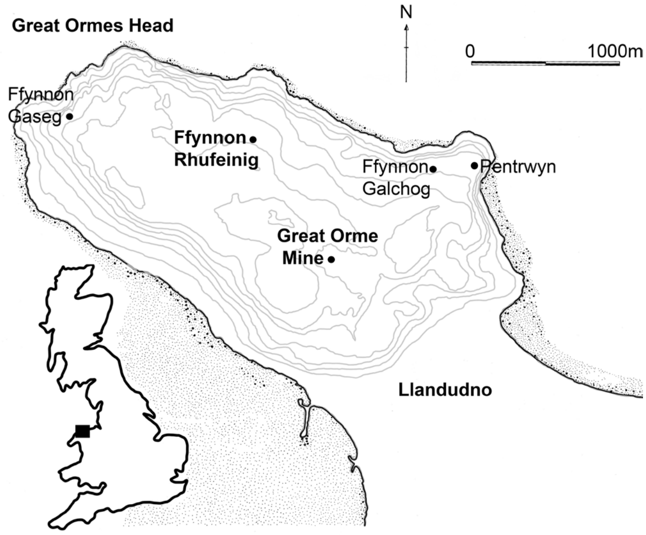


Figure 6: Map of the Great Orme, north Wales, showing places mentioned in the text.

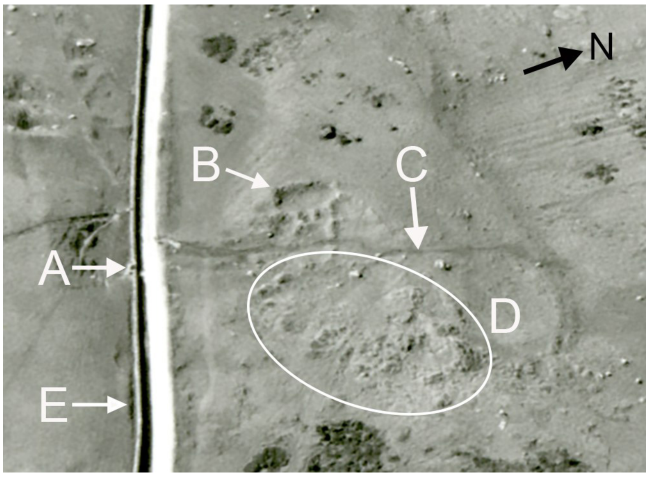


Figure 7: Aerial photo showing landscape features at Ffynnon Rhufeinig. A: modern well-head, B: rectilinear feature (not excavated), C: present stream course, D: mounds and hollows where excavations were carried out, E: modern farm road and boundary wall. Image width approx 110m.

There is a strong local tradition for copper ore washing at Ffynnon Rhufeinig during the pre-modern period. The recovery of tons of *copper slime* for smelting is recorded in this area during the 19th century and later newspaper reports refer to the 'yellow stain of copper washing' still being visible in the early 20th century (Roberts 1909). More recently, the construction of the modern well-head, adjacent farm wall and road is likely to have caused further disturbance (Hopewell 2013). Aerial photographs of this part of the Orme reveal a number of low mounds and hollows to the east of the modern stream course (Fig 7). In 1996, the authors, with a small team from the University of Sheffield, carried out a topographic and vegetation survey in the area to the north of the modern well-head. This identified a series of shallow gullies, embankments and regularly-shaped shallow depressions, as shown in Figure 8.

Significantly, surface scatters of *rotted* orangey-yellow dolomitic limestone and malachite ore nodules were picked up from patches of disturbed ground on and around the mounds. The well at Ffynnon Rhufeinig is situated on grey limestone. Consequently, finds at that location of orangey-yellow dolomitic limestone are evidence for the deliberate transport of rock to the well-head from elsewhere. The presence of malachite

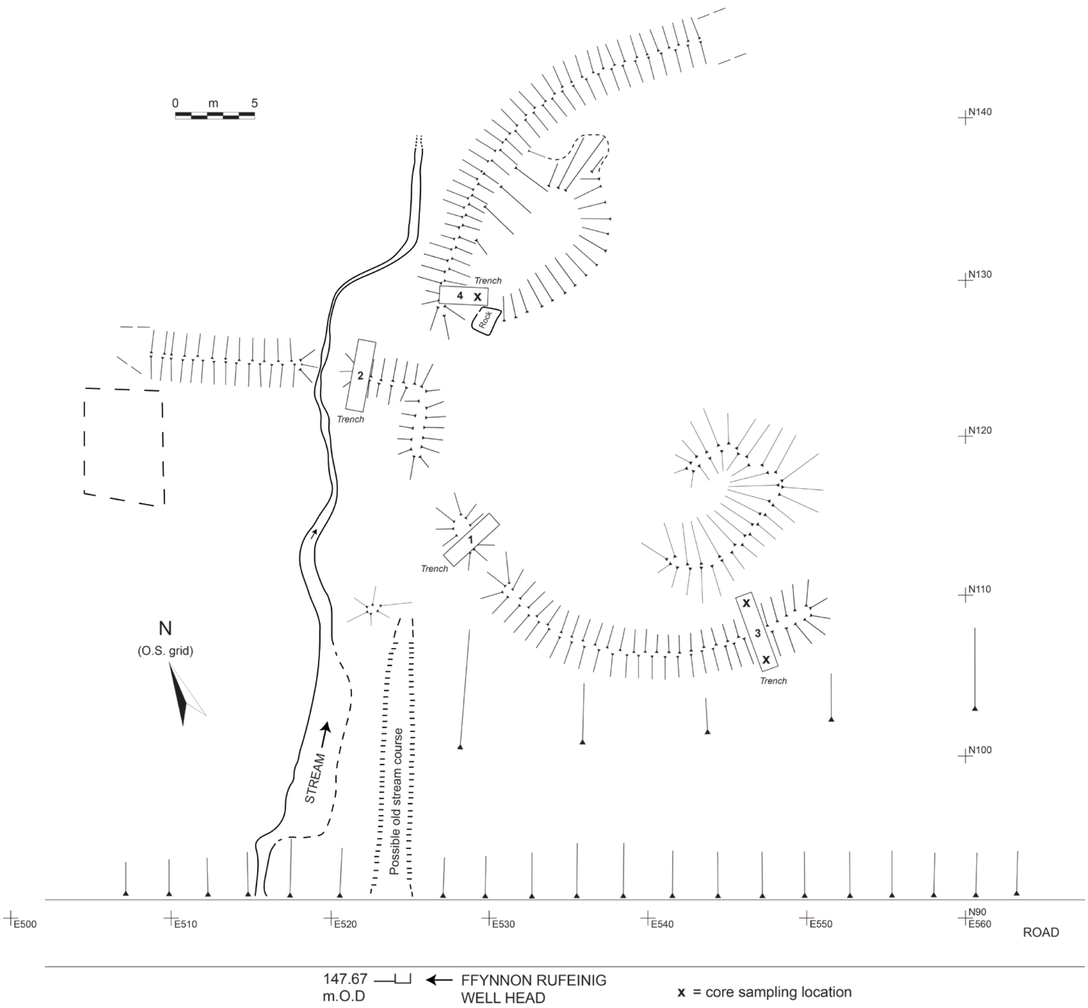
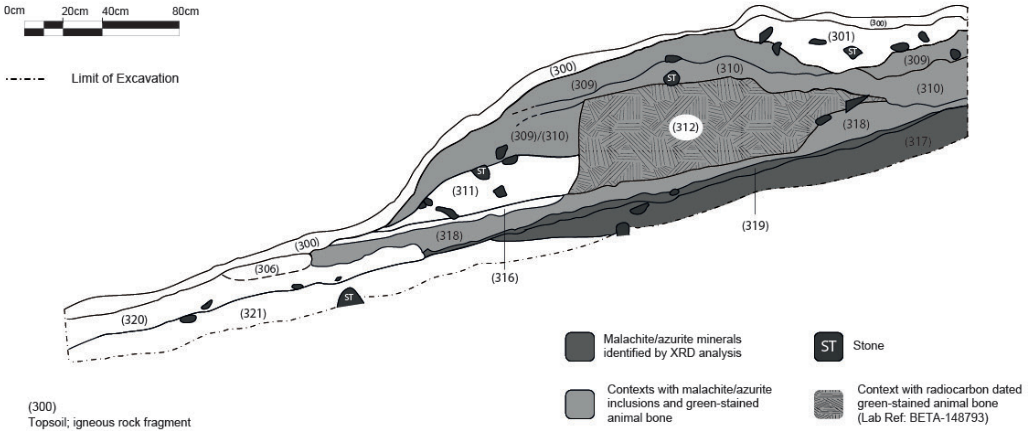


Figure 8: Ffynnon Rhufeinig site plan, showing the locations of the four trenches and the core samples taken from them.



(300)
Topsoil; igneous rock fragment (possible spall); green-stained animal bone (1)

(301)
Mid-brown loose silty sand; malachite staining

(306)
Grey-brown loose sandy clay with frequent (90%) gravel, malachite/azurite

(309)
Intermingled yellow-brown firm silty sand to mid-brown friable sandy silt; malachite/azurite; green-stained animal bone (2)

(310)
Orangey-brown loose silty sand; malachite/azurite; green-stained animal bone (10)

(311)
Blackish-grey loose clayey silt

(312)
Intermingled dark brown-orange mottled stiff/sticky clay, yellowish sand and gravel; malachite/azurite; green-stained animal bone (13)

(316)
Dark-brown friable silty clay

(317)
Pinkish-grey plastic silty clay, charcoal flecks

(318)
Orange-brown loose sand; malachite/azurite; green-stained animal bone (1)

(319)
Dark grey-brown orange-mottled plastic silty clay; occasional shells; rare charcoal flecks

(320)
Yellow-brown firm clayey sand with frequent (70%) pebbles

(321)
Mottled orangey-brown firm clayey silt

Figure 9: Ffynnon Rhufeinig Trench 3, west-facing section.

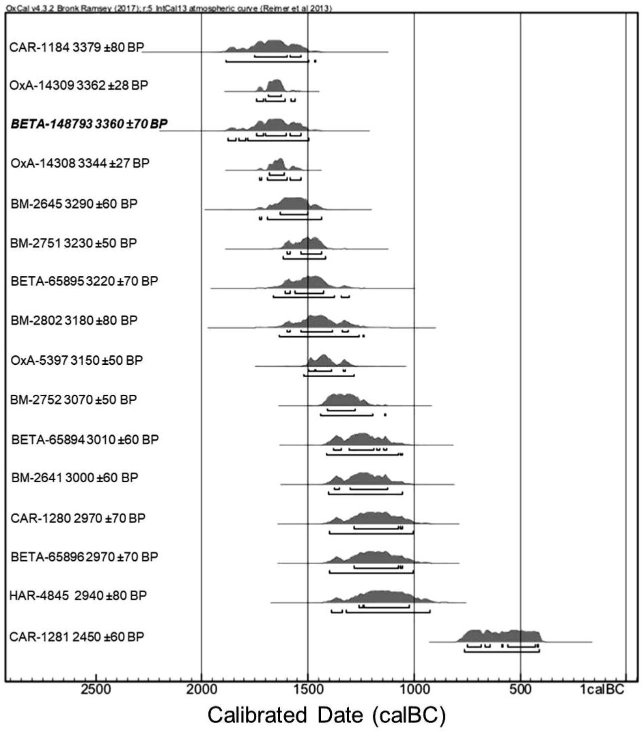


Figure 10: Comparison of the radiocarbon date from Ffynnon Rhufeinig (in italics, third line down) with the available dates from the Great Orme mine workings (recalibrated from James 2011; Bronk Ramsey 2009).

is consistent with the mine workings being the most likely source of this material. A geochemical survey using a portable hand-held X-ray fluorescence analyser furthermore identified hotspots of copper concentration in excess of 3000µg/g associated with the earthworks, compared to background values of 100µg/g (Wager *et al* 2002).

The vegetation on and around the earthworks was predominately dense bracken with concentrations of thrift (sea pink or *Armeria maritima*). The low plant diversity indicates that this plant community had not been long established. *Armeria maritima* is a sub-metallophyte, *ie* a plant species that grows in areas of heavy metal pollution, particularly where the ground has also recently been disturbed. However, as it is a coastal plant, its occurrence at Ffynnon Rhufeinig, whilst indicating mining activity, could be due to a combination of factors (Ary and Gregory 1965; Buchanan 1992).

A small-scale excavation was then undertaken within an area approximately 40 by 40m. Four trenches, from 3m to 5m long and 1m wide, were positioned to investigate the principal surface features (Fig 8). Trench locations were chosen with the aid of the results from a small-scale coring survey, in which 50mm diameter cores were removed at 10m intervals across the site. The number and size of the trenches were restricted as the area is a Site of Special Scientific Interest (SSSI) as it is a breeding ground for Fritillary butterflies. The most significant findings for the study of Bronze Age ore washing were recovered from Trenches 3 and 4.

Trench 3 was orientated N–S across a substantial embankment close to the present stream course (Fig 8). The vegetation covering the embankment was characterised as unimproved meadow, indicating a lack of recent

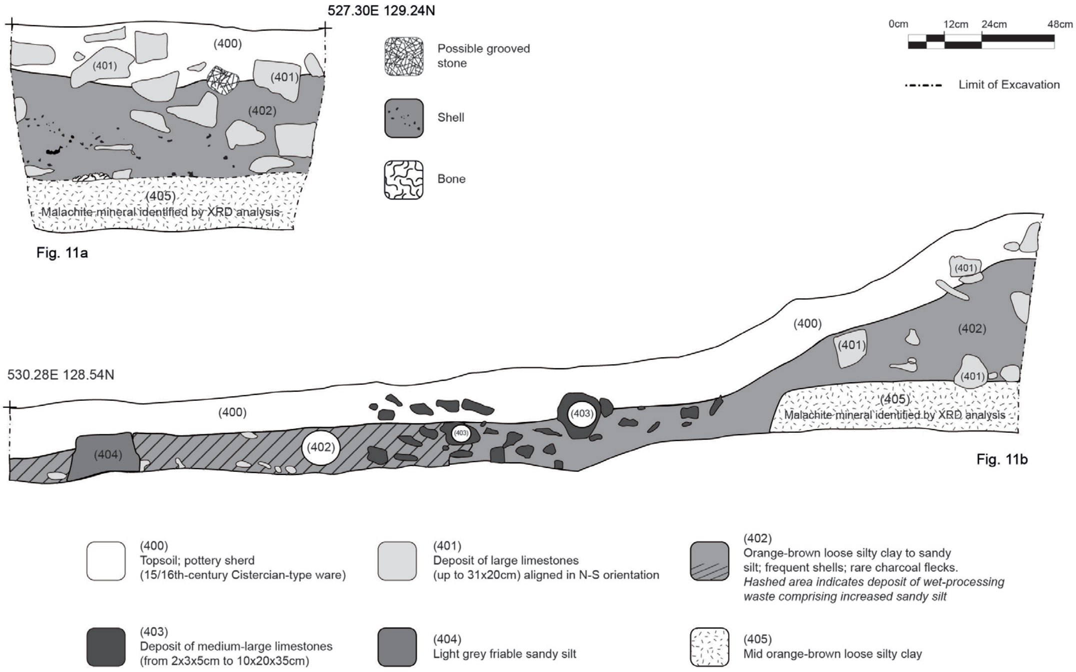


Figure 11: Ffynnon Rhufeinig Trench 4, a) east-facing section, b) north-facing section.

ground disturbance, with species typical of calcicolous (limestone) soil environments and frequent *Armeria maritima*. Pre-excavation cores taken from the mound comprised layers of silty sand and clay, with rare dolomitic limestone inclusions and charcoal flecks.

Excavation in Trench 3 identified a complex succession of well-sorted orangey-brown dolomitic-limestone sandy and silty layers, with intermingled lenses of clay and gravel (Fig 9). Inclusions included malachite ore fragments; finely-disseminated charcoal; a single igneous rock fragment, possibly a spall from a stone hammer; and 27 animal bone fragments, stained blue-green by impregnation with copper minerals. The proportion of green-stained bone increased from 33% in the topsoil to 100% in the layers of well-sorted sands and silts. Post-excavation X-ray diffraction (XRD) analysis confirmed the presence of malachite. Using criteria developed by other researchers for the field identification of Bronze Age mining spoil, plus the published results of experimental ore processing (*eg* Modl 2011; 2015), the Trench 3 deposits are interpreted as waste from the washing of prehistoric mining spoil.

Significantly, two samples of green-stained animal bone from a distinct undisturbed layer of well-sorted washing waste in Context 312 in Trench 3 (Fig 9) gave a radiocarbon age of 3360 ± 70 BP (Beta – 148793), which corresponds to a recalibrated date of 1877 to 1499 cal BC (at two sigma) (Ottaway and Wager 2000; Bronk Ramsey 2009). This material can therefore be assigned to the earliest known phase of mining on the Orme (Fig 10). It shows that mining spoil of Bronze Age date had been deliberately transported a distance of less than a kilometre from the mine workings to the water source at Ffynnon Rhufeinig for wet ore separation.

Context 312 was sharply cut (Fig 9) and there was other evidence of disturbance, such as the mixing of sandy and silty layers with clay and gravel inclusions. This points to the reworking of an existing heap of Bronze Age spoil, with material being dug out and redeposited, most probably on more than one occasion. At some point, natural erosion appears to have caused the waste deposits to slump into the observed cut, resulting in the present form of the embankment.

Trench 4 bisected a low curving embankment and adjacent shallow depression downslope from the modern well-head, within an area of bracken vegetation (Fig 8). Pre-excavation coring recovered fine silty clay from the base of the depression. Excavation indicated that this pond-like feature had been cut into the underlying natural, with stones and earth then being piled up to create a substantial embankment around its edge (Fig 11). More stones appear to have been positioned flush to the surface of the shallow depression, possibly as a form of lining. Within the depression were found both disturbed and primary deposits of fine-grained dolomitic sandy silt/silty clay with rare charcoal flecks. Post-excavation XRD analysis verified the occurrence of malachite and azurite within these sediments. There was no direct evidence dating the features in Trench 4, although the deposits within the shallow depression are, like those in Trench 3, characteristic of prehistoric ore-washing waste.

The excavated features in Trench 4 are interpreted as a system of channels and pools. In the latter, the mined ore, probably after preliminary crushing and/or grinding at the mine itself, was agitated in running water from the nearby spring to separate the waste rock from the desired ore minerals by exploiting the difference in their relative densities. The gently sloping terrain at the site would have facilitated control of the water flow through the leats and pools. As the crushed ore feed of equal particle size entered into the flow of water, the denser copper-rich fraction would have settled out first. The less dense dolomitic limestone waste would have moved further before settling out as the water flow slowed down, producing the layers of fine sediment in the pool excavated in Trench 4. Successive phases of removal of this material would over time have produced the mounds of washing waste lying at the head of this system, such as that excavated in Trench 3. These waste deposits appear to have been reworked repeatedly, most likely to retrieve ore remaining from earlier episodes of wet processing.

Discussion: Optimal versus minimal preservation

The wide range of material from the first case-study area, in the Austrian Eastern Alps, is due primarily to the waterlogged anaerobic environment at all three sites, which created ideal conditions for the preservation of wooden artefacts. By detailed palynological study and experimental replication of the preserved wooden finds, it has been possible to reconstruct the environmental context and task sequence of activity at each site, and to associate these findings with absolute dates from dendrochronology. The Austrian sites were all recently investigated as part of well-defined, multi-disciplinary, grant-supported, long-term research projects, such as the History of Mining Activities in the Tyrol and Adjacent Areas (HiMAT) project (*eg* Goldenberg *et al* 2012; Anreiter *et al* 2013; Stöllner and Oeggl 2015). This involved a unique co-operation of at least 12 specialists from different scientific fields. The level of detail of the findings from Troiboden, Bachalm and Mauk F is testament to the power of this approach for research into prehistoric metal production.

In contrast, the neutral to slightly alkaline groundwater conditions on the Great Orme inhibit the preservation of wood. The rich diversity of material evidence needed to reconstruct fully the methods and sequence of prehistoric ore washing at Ffynnon Rhufeinig is consequently lacking. To identify wet ore separation in areas of minimal preservation, such as the Great Orme headland, complex deposits of waste rock and sediment have to be interpreted using criteria derived from geo-environmental and archaeological studies of early mining spoil combined with data from experimental reconstruction of potential prehistoric ore-processing methods. In the absence of cultural material such as pottery, dating of this evidence relies on the recovery of samples of well-preserved bone or charcoal associated with the deposits of presumed prehistoric ore-washing waste.

Additional field investigation at Ffynnon Rhufeinig could, however, establish more securely the date, phasing and extent of all the features at this site. Ideally, this should be undertaken as part of a programme of research into all of the other potential prehistoric ore-washing sites on the Great Orme, including a reappraisal of Ffynnon Galchog and Ffynnon Gaseg (Fig 6) (Lewis 1990; Wager 2002). One of the aims of this research should be to look for any evidence for ore washing on the headland during the main phase of mining there during the Middle Bronze Age, as this has not so far been identified. Ffynnon Gaseg is undated, while a sample of bone from the 1990 excavation of one of the waste tips at Ffynnon Galchog gave a recalibrated radiocarbon date of cal AD 682–969 (at two sigma) (Bronk Ramsay 2009; Jones 1994; Lewis 1990; 1996). This site shares many characteristics with Ffynnon Rhufeinig – including surface water flow and waste tips comprising sequences of graded dolomitic silts, sands and medium gravels with copper-stained bone fragments – and so the Early Medieval date could be due to sample contamination.

Impact: Understanding prehistoric copper metal production on the Great Orme

The findings to date from Ffynnon Rhufeinig are significant for our understanding of prehistoric mining in Britain and Ireland. The radiocarbon date of 1877 to 1499 cal BC (Beta – 148793) obtained from the sample of bone associated with the deposits in Trench 3 is contemporary with the earliest known phase of copper mining on the headland (Fig 10). This is so far the only example of ore-washing waste from Britain and Ireland to have produced a Bronze Age date. It points to the washing of ore having taken place close to the stream at Ffynnon Rhufeinig in the Early Bronze Age. It suggests that, in the earlier phases of production, the Bronze Age miners did not confine their activities to the immediate vicinity of the mine itself but exploited the wider landscape of the Orme and its resources to carry out the tasks involved in copper production. A similar strategy is evident in the Late Bronze Age, from the limited evidence for small-scale copper smelting at nearby Pentrwyn, on the headland 1.2km to the W of the mine (Smith *et al* 2015). Repeated later phases of reworking of the earlier deposits at Ffynnon Rhufeinig resulted, over time, in the surface features visible at the site today.

The ore-washing site at Ffynnon Rhufeinig is crucial to our understanding of the Great Orme as a complex multi-phase copper mining landscape, known to have developed from the early 2nd millennium BC onwards. It enables us to reconstruct in more detail the techniques and spatial organisation of ore treatment during the earliest known phase of mining on the headland and to interpret the evidence from the mine within its specific contemporary landscape and historic context – a fundamental step towards a socioeconomically informed model of prehistoric metal production (Wager 2002; O'Brien 2015). The latest Archaeological Management Plan for the Orme, which was published nearly 20 years ago, identified topographic and geophysical survey at Ffynnon Rhufeinig as a high priority (Gwynedd Archaeological Trust 2001). Since then, however, this archaeologically sensitive area has been damaged by a succession of large fenced enclosures, approximately 16m by 18m and 2m high, constructed from solid timber posts of 150–200mm diameter. It is imperative that Ffynnon Rhufeinig and other potential ore-washing sites on the headland receive better recognition and stronger environmental protection. Otherwise, we will lose a unique opportunity to study a vital step in the sequence of metal production at the Great Orme mine, a site of enormous importance for understanding the British Bronze Age.

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