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Cobble Stone Mining Tools - Evidence of Their Use in the Bronze Age Mines of Britain and in Current Archaeological Experiments Investigating Ancient Mining and the Processing of Metal Ores

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Keywords

Early Bronze Age, copper mines, Wales, hammerstones, firesetting, mining experiments, ore processing, gravity separation

Abstract

The characteristic artefacts of Early Bronze Age metal ore mining are cobble stone mining tools. The current study suggests that within these tool assemblages it is normal to see some sort of use specialisation and opportunistic re-use of broken tools, whilst the wear pattern and modification to these suggests the creation of *ad hoc* tool kits, and the use of both hand-held and hafted hammers. At some of the sites more than 90 % of cobbles used show only minor evidence for purposeful modification (such as a pecked groove designed for hafting), yet extensive experimentation has demonstrated that many of these tools could have been, and probably were used with handles. Some sort of discrimination in the collection of cobbles at source is suggested by the evidence for consistency in size, shape, weight and lithology of the stones. In West Wales we find suitable cobbles brought up to 25 km inland from the storm beaches on the coast to be used at these upland sites. Experimental archaeology has been successful in predicting the types of tools to be found during the archaeological excavation of sites; this includes the use of antler picks and bone scrapers and chisels which often don't survive within acidic mining environments. As regards stone tools, experiments have also shown how the most rudimentary artefacts might be used in the processing and concentration of metal ores, including those of copper and gold. The current paper presents a body of archaeological evidence and experimental research, which is likely to be universally relevant to the study of some of the most ancient mines and mining areas in Europe.

Introduction

Recent finds of Bronze Age mining tools and metal mines in Britain

Over the last twenty years the discovery and excavation of some fifteen Bronze Age metal mines or prospecting sites, and the probable identification of at least eight others within England and Wales have provided a suitable timeframe for the first exploitation of metal within the UK (Timberlake, 2009a) (Figure 1a). This activity consisted of a widespread phase of early prospection taking place between 2000 and 1650 BC followed by production at a very limited number of sites (such as the Great Orme in North Wales (see Dutton and Fasham, 1990; Lewis, 1996), which continued right up until the Late Bronze Age. All of these investigations, except for those undertaken on the Great Orme form part of a long term programme of study currently being undertaken by the Early Mines Research Group (EMRG) (note the stone and bone tools from the Great Orme Mine, Llandudno are mentioned in this paper but are not described in any detail – see instead: Gale, 1995; Lewis, 1996; James, 2011; Williams, 2023).

Bronze Age workings have been identified at **Parys Mountain** on the northeastern corner of Anglesey (Timberlake, 1990a; Jenkins, 1995; Jenkins, et al., 2021) (Figure 2). 'Primitive' style surface workings mined using stone cobble tools and with brushwood fires were reported in 1796 (Briggs, 1976). One small area of this was re-located in the 1930s, and then subsequently re-excavated and dated by the present team in 1988. More recently several prehistoric workings have been discovered

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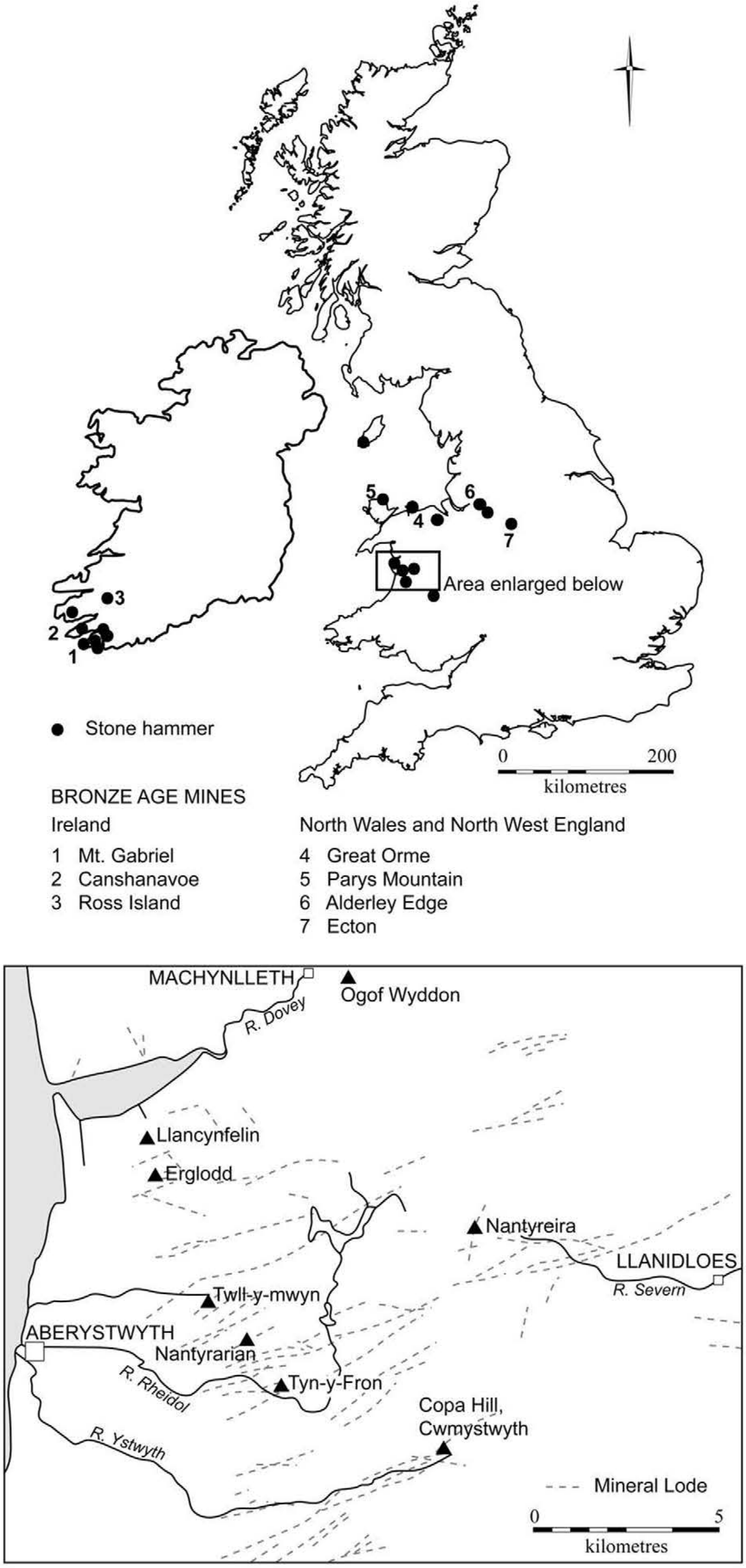


Figures 1a and b. Map showing cobble stone mining tools and Bronze Age mines in Britain and Ireland. Note the inset Figure 1b shows the prehistoric mines and mineral veins of the Central Wales Orefield. Illustration: S. Timberlake and B. Craddock.

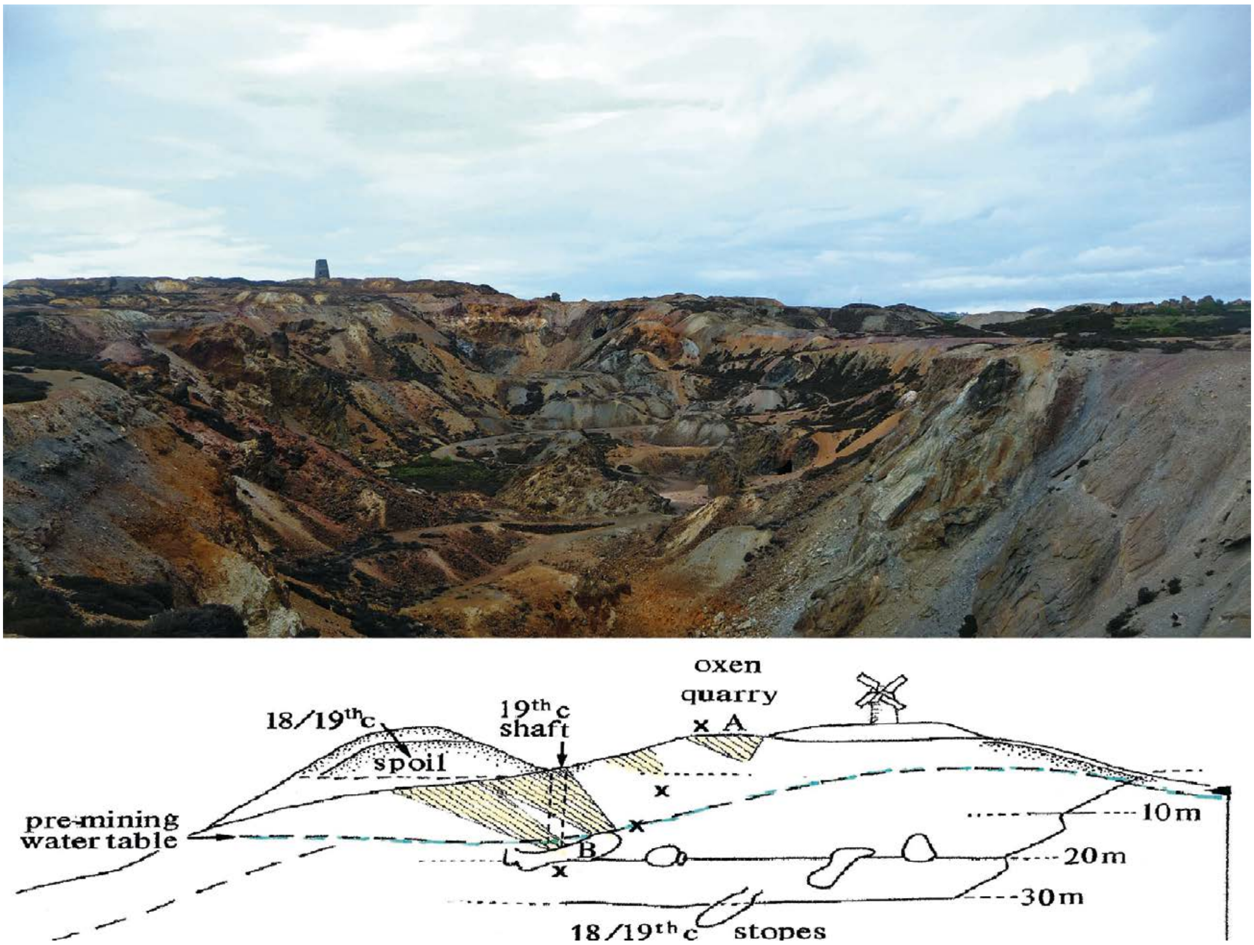


Figure 2. Parys Mountain, Anglesey (photograph) and schematic section (beneath) showing the location of the Bronze Age opencast drift workings.

and excavated underground by David Jenkins at the points where these drifts intersect with the roofs of nineteenth century levels and stopes at depths of around 5 m to 50 m below surface. The form of these deposits seem to suggest repeated working and subsequent redeposition of worked mine spoil within a series of steeply inclined opencasts dug on surface weathered portions of quartz stockwork veins. The discovery of lumps of native copper weighing up to 15 kg within the upper portions of these veins during the re-working in the 1780s (Lentin, 1800) attests to the ore which might have been sought here in prehistory.

The largest group of eight Bronze Age mines, the majority of which are little more than prospection sites is to be found within the Central Wales ore field, all of them associated with small, discontinuous, near surface pockets of copper ore (chalcopyrite) upon SW-NE trending lead-zinc-silver veins (see Figure 1b). Most of mines appear to be grouped within distinct prospection zones, which it is surmised might relate to the rapid tree clearance and erosion which took place during the Early Bronze Age associated with the expansion of transhumance pasture. As a result of this deforestation e and loss of soil cover the weathered tops of some of these quartz-ankerite veins, with their distinctive rusty brown and blue-green coloured copper and iron minerals, became visible outcropping on the steep valley sides. Such a means of discovery was probably the case at **Copa Hill (Cwmystwyth)** within the south-east of the orefield (Figure 3). Here a rich pocket of ore present within the top of the Comet Lode (at 426 m AOD) was exploited during the Early Bronze Age between 2100-1600 BC by means of opencasting to a depth of over 10 m (Timberlake, 2003).

Archaeological excavations carried out here between 1989 and 1999 revealed a moderately large prehistoric working from which some 5000 tonnes of rock appears to have been removed using firesetting and stone tools, with the production of 1-6 tons (Timberlake, 2009a) to as much as 7+ tons of copper metal (Timberlake, 2009b). Artefacts recovered from the waterlogged mining sediments infilling the opencast include antler picks and hammers, twisted hazel (withy) ropes and handles for hafted stone tools, basket fragments, mine timber (stem-

Figure 3. Comet Lode Opencast Bronze Age Mine, Copa Hill, Cwmystwyth. Photo: S. Timberlake.

ples and cut firewood) plus several well-preserved wooden launders (Figure 4) and more than a thousand cobble stone mining tools. A mineralogical study of the ancient mine spoil and the remaining mineral vein within the mine appears to confirm that a weathered chalcopyrite ore intermixed with galena was being exploited here. Finely crushed (< 3 mm diameter) grains of goethite present within the mine spoil contain un-oxidised cores of chalcopyrite, suggesting it was this fraction of the ore that was being sought and crushed, perhaps to release copper in the form of the associated malachite and copper oxide; minerals that were much more easily smelted than the un-altered sulphide. However, no trace of any smelting hearths have been found during the wider archaeological examination of this site, and it is assumed that these lay elsewhere, and that instead ore concentrate left the mine, which may have been taken to metalworkers at the end of each mining campaign.

Subsequent to the discovery and earliest working of the mine on Copa Hill, the prehistoric miners appear to have followed the course of the Comet Lode westwards, beyond the point where this had been downfaulted and displaced by the Ystwyth Fault. The chalcopyrite exposed at outcrop to the west of here appears to have been completely altered to an iron gossan, perhaps because of its associated pyrite content, though beneath this there may have survived both oxidised and other supergene copper minerals. It is no surprise therefore that another prehistoric mine was discovered here in 2017 at **Penparc (West Cwmystwyth)**, approximately one and a half kilometres to the east of Copa Hill, and a short distance above the valley road (Timberlake and James, 2018). This smaller mine probably dates to the same general period, but to a shorter period of working (i.e. the radiocarbon dates suggest 1928-1696 BC). Though lower down and some distance along the valley side, the site is still intervisible with the main opencast working on Copa Hill (seen here on the skyline in Figure 5). Mining tools recovered from the Penparc working include stone pounders, ore crushers, anvils plus stone hammer flake/ micro-use wear debitage. The recovery and recording of the latter has proved interesting, and this is described in more detail within the section on the analysis of cobble stone tools.

In 2014-2015 the archaeological team of the EMRG re-investigated **Nantyeira (Snowbrook) Mine** in the Hafren Forest on the east side of Plynlimon. Located at an altitude of c. 500 m AOD, this is one of the most isolated mines in mid-Wales (Figure 6). We first looked at this site in 1988, as it was a strong contender for early

Figure 4. Section of the Early Bronze Age alder wood launder left *in situ* within the 1995 archaeological excavations of the Comet Lode Opencast on Copa Hill. Photo: S. Timberlake.

mining, with finds of both antler and stone tools at the time of its re-discovery and re-working in 1859. In 2014 we excavated a further eleven test pits, most of which encountered fireset mine spoil containing stone tool fragments (Timberlake and Haylock, 2018). The investigation revealed that the prehistoric opencast extended for more than 100m along the outcrop of the vein, confirming that this was a larger Bronze Age mine than previously thought. Its location here is interesting, given that the mine is situated on the spot where a strong mineral vein has been cut by the gorge of a mountain stream feeding the River Severn; the site lies only a short distance below the source of this major British river and on the margins of an Early Bronze Age burial landscape. The stone tool procurement strategy employed at this mine is interesting.

Because of the mountain barrier separating this particular group of mines from the coast at Cardigan Bay the miners simply used what was immediately available to hand within this sparse glaciated landscape. To the west of Plynlimon, on the opposing watershed of the Cambrian Mountains, we tend to find evidence for the preferential use of beach cobbles brought from the coast. Considerable numbers of these were carefully-selected at source (according to size, shape and weight) then brought inland on the backs of cattle along the valley routes at the start of each mining campaign. We believe that the miners may have been transhumant pastoralist peoples who engaged in mineral prospection/mining during the summer months, extracting ore as a means to enter into the exchange economy and have access to finished metal goods (Timberlake, 2001, p.185; 2009a, p.112, 118). On occasion, the carriage of cobbles inland resulted in the excessive deposition of stones at these sites, though more typically we see their re-cycling on account of temporary shortages in suitable tool material. In contrast to this, the assemblage recovered from the more isolated, but nevertheless important mine at Nantyreira consisted for the most part of locally-sourced river cobbles and a smaller number of less well-rounded erratic stones removed from the neighbouring glacial moraine. However, there are also some examples of 'quarried' stone tools crudely-fashioned from the surrounding bedrock. The latter are only found in the mines worked in the upper reach-

Figure 5. Copa Hill from the Penparc (West Cwmystwyth) Bronze Age mine. Photo: S. Timberlake.

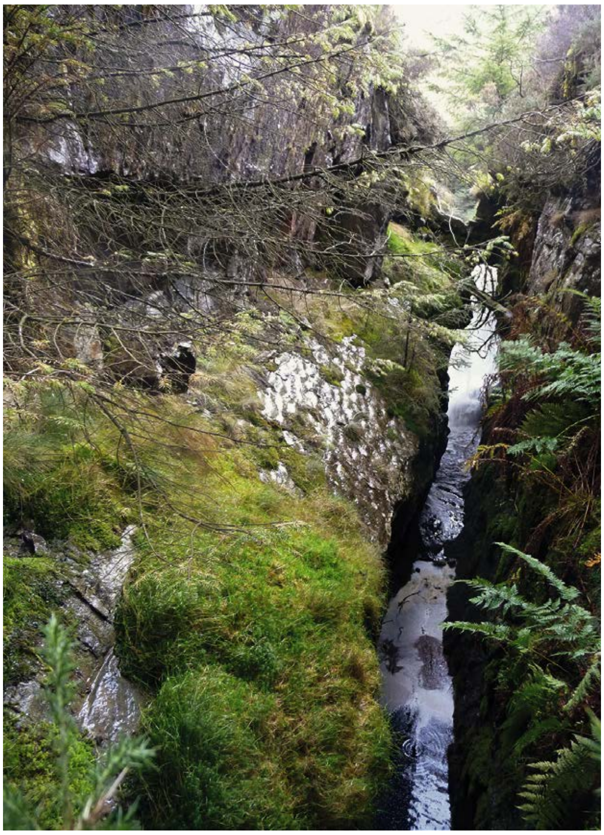


Figure 6. Ancient opencut at the Nantyreira Mine, Hafren Forest, Plynlimon. Photo: S. Timberlake.

es of the River Severn. These are described more fully within the general description of stone tools and their context.

In contrast to the above geological setting for prehistoric mining in Wales are the Bronze Age mines, which exploited copper ore deposits present within the Triassic sandstones of Alderley Edge in Cheshire (Timberlake and Prag, 2005). Three, possibly four sites have now been identified, with another at the nearby village of Mottram St. Andrew. The best surviving site is to be found at **Engine Vein (Alderley Edge)** where Early Bronze Age pit workings were investigated at the beginning of the 20th century (Roeder and Graves, 1905), but then archaeologically examined in 1998 (Timberlake and King, 2005) (Figure 7). These small mines and prospection sites were worked between 2000 and 1750 BC. Most consisted of shallow benched pits connected in places by opencuts dug to extract the thin discontinuous lenses of malachite, azurite and other minerals deposited in between beds of baritised sandstone, conglomerate and mudstones of the Engine Vein Conglomerate (Sherwood Sandstone Group). In fact there are two quite distinct but nevertheless related deposits of oxidized copper minerals here; one concentrated along the bedding planes of the sandstone, forming richer pockets closer to the mineralising faults, and another one which was copper-poor yet more easily workable, consisting of small nodules of malachite and azurite scattered throughout the intervening mudstone. Prior to the Bronze Age the site may have been an important source of colourful pigments in the form of yellow pyromorphite, black manganese wad, and

Figure 7. Bronze Age pit working under excavation at Engine Vein, Alderley Edge, Cheshire in 1997. Photo: S. Timberlake and the Alderley Edge Landscape Project (AELP), The Manchester Museum.

Table 1. Prehistoric copper mining sites in West Wales investigated by S. Timberlake and the EMRG between 1986 and 2020: a summary of the archaeology and published references.

Mine	Location	Finds/ sampled	Discovery/excavation	References	Date range (^{14}C at 95%)
Balkan Hill	Aberdovey, Merioneth	-	Mined 1823	Bowen and Gresham, 1963; Pickin, 1990	Bronze Age?
Panteidal	Aberdovey, Merioneth	Mauls, 30m opencast, 'water races'	Discovered 1899; surveyed/trenched 1996: no finds, but sample dated 2019 and site re-surveyed in 2020	*Mining Journal,* 1899; Timberlake, 1996a (*AW*36); Timberlake, et al., 2019 (*AW*59,117-119)	1929-1753 cal BC [Beta-536847]
Park Lodge (Ogof Wyddon)	Machynlleth, Powys	Mauls, opencast, tip, charcoal (^{14}C)	Discovered 1856; trench excavation 1997	RCAHM(W) 1911; Timberlake and Mason, 1997 (*AW*37, 62-65); Timberlake, 1998 (*AW*38, 80)	1890-1630 cal BC [BM-3146]
Llancynfelin	Trer-ddol, Ceredigion	3 sites: site A (Borth Bog) 44 mauls, mortar, ^{14}C charcoal	Mined 1800s; trenched 1992, peat core 2003	Bick, 1976; Timberlake, 1992 (*AW*32, 90-91); 1995 (*AW*35, 42-43)	1745-1645 cal BC [BM-2916]
Pwll Roman	Tre-Taliesin, Ceredigion	West edge of Borth Bog: mauls	Mined 1852; surveyed 2004	Timberlake, 2004a (*AW*44, 142-143)	Bronze Age?
Erglodd	Talybont, Ceredigion	NW edge Borth Bog: mauls, charcoal (^{14}C)	Mined 1800s; surveyed/trenched 2005	*Mining Journal,* 1869; Hughes, 1981; Timberlake, 2006 (*AW*46, 82-85)	2340-2130 cal BC [Beta-214364]
Twll y mwyn (Cwm Darren)	Penrhyncoch, Ceredigion	>50m long opencast, mauls, charcoal (^{14}C)	Stone tools discovered in 1744; surveyed/ trenched 2005	Lewis Morris (1744) in Bick and Davies, 1994; Timberlake, 2006 (*AW*46, 79-82)	1910-1700 cal BC [Beta-214943]
Nantyrarian	Goginan, Ceredigion	Opencast, tip and mauls, charcoal (^{14}C)	Tools discovered in 1866; surveyed/ trenched 1992	*Cambrian Arch. Ass.,* 1866; Williams, 1866; Timberlake, 1992 (*AW*32, 91); 1995 (*AW*35, 43-44)	1885-1735 cal BC [BM-2930]
Tyn y fron	Cwmrheidol, Ceredigion	Opencast, tip (track section), mauls, charcoal (^{14}C)	Tools discovered in 1744, mined 1900s; surveyed/ trenched 1996	Smyth, 1848; Bick and Davies, 1994; Timberlake 1996b (*AW*36, 61-63)	2135-1885 cal BC [Beta-120592]
Nantyreira (Snowbrook)	Plynlimon, HafrenForest, Powys	Opencast >50m, mauls, mortar, charcoal (^{14}C)	Discovered 1859; dug 1937, trenched 1988; re-surveyed and test-pitted in 2014	Jones, 1922; Davies, 1937; 1938; Timberlake, 1988 (*AW* 28, 14-17); 1989 (*AW*29, 41-42); 2018 (*AW*57-58, 173-178)	1856-1610 cal BC [BM-2583] & 1900-1745 cal BC [Beta-434950]
Nantyricket	Plynlimon, River Severn, Powys	Opencast, washed-away tip, mauls	Discovered 1800s	Jones, 1922; Davies 1937; Timberlake 1990; 2018 (*AW* 57-58, 178-181)	4707-4551 cal BC [SUERC-59891] (Neolithic/EBA?)
Grogwynion	Pontrhydygroes, Ceredigion	Maul	1987 survey	Thorburn, 1990	Bronze Age casual prospection?
Copa Hill, E. Cwmystwyth (Comet Lode Opencast)	Cwmystwyth, Ceredigion	Opencast 10m+ deep and tips; mauls, antler tools, wooden launder, withies; wood, charcoal (^{14}C)	Discovered 1813; tips trenched 1930s and 1986, excavated 1989-1999	Smyth, 1848; Jones, 1922; Davies, 1947; Timberlake, 1987 (*AW*27, 18-20); 1990c; 2003 (*BAR* 348); 2004 (*AW*44, 139-141)	x 25 ^{14}C dates: approx. range 2100-1600 BC
Penparc, W. Cwmystwyth (Penparc (Comet) Lode opencuts)	Cwmystwyth, Ceredigion	Series of shallow infilled opencuts upon narrow vein outcrop; stone mauls + flakes, charcoal	First noticed in 2015; trenched + excavated in 2017	Timberlake, S. and James, D. 2018 (*AW*57-58, 91-100)	1881-1696 cal BC [SUERC-77026] & 1928-1769 cal BC [SUERC-77027]

of green and blue copper carbonates; a theory supported perhaps by the presence of Mesolithic hunting camps on top of, or else close to the later sites of mineral extraction (Timberlake, 2009b).

Within the last 5-6 years, several Bronze Age workings have been located on Ecton Hill, a limestone peak on the eastern side of the Manifold Valley in Staffordshire, Central England (Timberlake, 2014). A prehistoric date for old workings associated with these rich 'pipes' of copper ore outcropping on the hilltop ridge was first suggested following the discovery of a part-worked antler point by the archaeologist John Barnatt during underground exploration of **Dutchman (Stone Quarry) Mine, Ecton** in 1997 (Barnatt and Thomas, 1998). Meanwhile the distribution of hammer stones at surface suggested the possible presence of Bronze Age mining at three different locations: Ecton Pipe, Stone Quarry, and The Lumb. Archaeological excavations were carried out at Stone Quarry and The Lumb in 2008 and 2009.

The Lumb workings lie close to the summit of Ecton Hill. Here one or more of the weathered limestone horizons have been dolomitised with secondary mineralisation in the form of vugh pockets and veinlets of malachite and goethite. This copper ore outcrop was followed along its strike by the Bronze Age miners before being dug down through a series of worked overhangs, some over 2 m deep (Figure 8). These overhangs eventually collapsed, or were intentionally undermined, as the workings extended back still further into the limestone. The sites of extraction were small, hand-picked and hammered-out hollows, some of them associated with splinters of bone and antler tools, and occasionally hand-held hammer stones. Subsequently some of the clay-filled fissures overlying this rock bed were opened to gain access via a series of short crawling passages to a number of mineral-filled solution features. These same ore-filled cavities appear to have been re-worked during the postmedieval period using firesetting, yet the presence here of occasional hammerstone batter marks attests to the former presence of prehistoric miners. Twelve bone and antler tools from the two sites of prehistoric mining have now been dated and statistically modelled. Collectively this provides us with a calibrated date range for the working period of the mines between 1880-1700 cal BC (start date) and 1760-1640 cal BC (end date). The slightly different date ranges for each of the two sites suggests that mining began at Stone Quarry and was of longer duration than that carried out on The Lumb (Timberlake and Marshall, 2013). However, it seems unlikely that mining would have lasted for more than a few decades at each.

Figure 8. Small Bronze Age mineworking within dolomitised limestone on The Lumb, Ecton Hill, Staffordshire. Photo: S. Timberlake and Early Mines Research Group.

Cobble stone mining tools: research, occurrence, context, analysis, terminology and recording

Recognition and study

The earliest mention of the discovery of stone hammers within the ancient mines of Britain was of a find made at Twll y mwyn (Cwm Darren) Mine in Cardiganshire, Central Wales in 1742. When lead miners working for Lewis Morris (the then Crown Mineral agent and antiquarian) re-opened this trench they found traces of burning and broken cobble tools, which Morris described as follows *"...the wedges were sea stones, with one end nipped off to an edge, and there is an impression on the other end where they used to strike on them….it seems (to me) the mine was worked before man knew the use of iron..."* (Bick and Davies, 1994). More than a century later William Boyd-Dawkins described the discovery of similar, although in this case grooved cobble stone tools within the pit workings at Brynlow Mine on Alderley Edge, which he described at the time *"...as perhaps belonging to the Bronze Age, when the necessary copper was eagerly being sought throughout the whole of Europe."*, noting the similarity of these to the Egyptian ones he had seen from the Sinai (Dawkins, 1875).

Sixty years later a rather more broad-ranging study of stone tools and primitive mining in Britain was undertaken by Oliver Davies for the British Association for the Advancement of Science (Davies, 1937). However, unable to date the charcoal, and with no pottery or artefacts, he referred to all of these mines simply as being "... *Roman or old Celtic in age.*"; concluding that the cobbles must have been either '*pounding stones*' or '*anvil-querns*', yet erroneously considered them to have been "...*broken to give better grip.*" (Davies, 1947).

Possibly the first modern study of these artefacts was undertaken by John Pickin in 1989/90. His typology consisted of 6 classes of cobble tools: unmodified (Type 1), surface-pecked (Type 2 a-d), edge-notched (Type 3 a-b), partially grooved (Type 4 a-b), single-grooved (Type 5) and multiple-grooved (Type 6 a-d) (Pickin, 1990). As a very simple classification of these tools, this typology still stands. Around the same time, David Gale was undertaking work for his PhD at Bradford University. This was a functional study of stone tools which examined both use-wear and cobble morphometry (Gale, 1995). Although comprehensive in its analysis, this work preceded most of the recent archaeological investigations of these sites, and involved no experiments or tool reconstructions.

Occurrence

The current distribution of cobble stone mining hammers at metal mines across the British Isles correlates with some (but not all) of the areas of near-surface copper ore deposits, particularly along the west coast of Britain (see Figures 1a-b). The results of recent fieldwork indicate the good survival of these tools, even where they have become dispersed as a result of redeposition through later mining. By and large an accurate assessment of the location and scale of Bronze Age mining comes down to skill in the recognition of what are sometimes really quite small fragments of unmodified tools.

Currently all of the archaeologically excavated and dated sites associated with *in situ* finds of cobble stone hammers have proved to be Bronze Age, despite the assertions of some sceptics that these tools, therefore the mines themselves, were medieval, or even modern - the explanation for the prehistoric dates being that firesetting was being carried out using fossil wood and peat (Briggs, 1988; 1993). However, alongside burnt wood, the radiocarbon dating of bone and antler mining tools as well as *in situ* formed organic deposits within the mines have all returned consistent results, conclusively indicating that the exploitation of these sites took place between the Early and Middle Bronze Age.

Figure 9. Grooved mining hammer (Type 2A) made from a glacial erratic cobble of Ennerdale Granopyre. Found at Pot Shaft, Engine Vein, Alderley Edge in 1997. Lenght approximately 180 mm. Photo: courtesy of the AELP archive, The Manchester Museum.

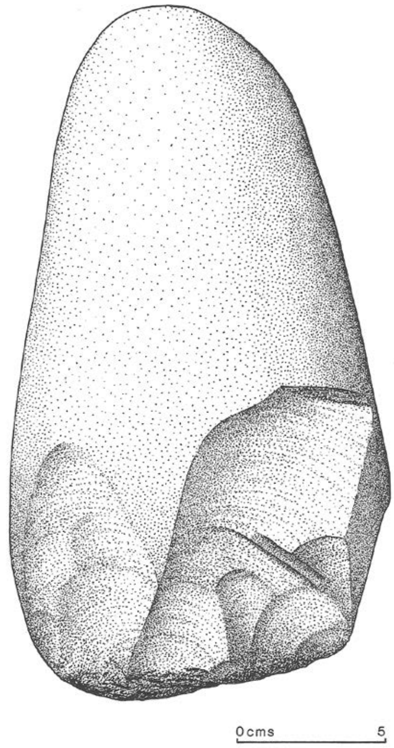


Figure 10. Type A un-modified cobble stone mining hammer from Copa Hill, Cwmystwyth; weight 2.25 kg. Drawing: B. Craddock.

Fully-grooved hammer stones, which elsewhere are commonly accepted as being prehistoric mining tools are rare in Britain; in fact within the British Isles grooved hammers have only been found at Ross Island, Killarney, Eire (O'Brien, 2004) and at Alderley Edge in Cheshire (Timberlake, 2005a) (Figure 9). There are none from Wales. Indeed, the much greater number of unmodified (Figure 10), or else minimally modified (Figure 11) cob-

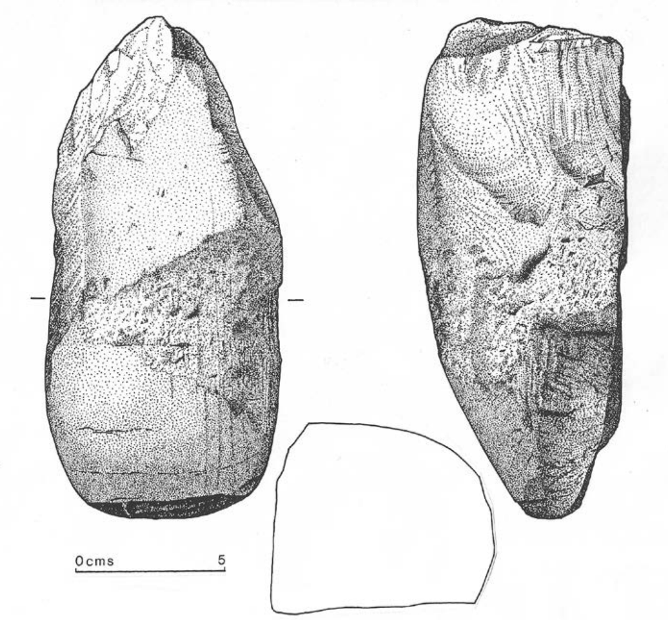


Figure 11. Archive drawing of notched to partially grooved cobble stone mining hammer made from greywacke. Copa Hill, Cwmystwyth; weight 1.475 kg. Drawing: B. Craddock.

ble tools at these Bronze Age mines may help to explain why so many of these sites have gone unrecognised, at least until the onset of the more systematic fieldwork carried out over the last three decades.

Given the evidence gained from experiments it is a little difficult to understand the reason why hammerstones from some sites were habitually grooved, whilst others weren't. This may be something that is cultural, typological, or associated instead with earlier (Chalcolithic) working. For instance, these tools are characteristic of the Beaker-dated mines of Ross Island (worked from 2400-1800 BC), yet they are also typical of Alderley Edge. Whilst it is still conceivable that the latter had early origins, the current radiocarbon chronology suggests this was mined later than the mines of West Wales i.e. the beginning of the 2nd millennium BC (Timberlake and Marshall, 2014) (Figure 12). The grooving of cobbles might instead be a response to a much greater investment in individual tools, which because of their competency and effectiveness against the host rock of the mine lasted longer, thus were worth maintaining and improving upon.

Context and significance

Hammerstone debris as a means to assess the proximity of mining activity

The presence of equal numbers of splinters and flakes alongside larger fragments of hammerstone within mine spoil would appear to indicate those places where the prehistoric mining evidence is well localised. In fact, this is a very good test of the *in situ* status of stone mining tools; for those cases where one might be attempting to date mining both above and below ground. Normally these tools are found broken-up and re-used; either present within the original mine spoil at surface, as purposeful backfill within the ancient workings, or as waste slumped down from the surface into underground cavities. Hammer stones, or fragments of hammer stones, are fairly indestructible, surviving any amount of later reworking. In most cases, these fragments of tools never disperse far from source, even when redeposited several times. In fact, experience has taught us that a complete size-range of broken tool fragments within the spoil is a very good indication for the near-by survival of other prehistoric mining remains, and sometimes of intact working areas. This is very useful knowledge to have when deciding upon the sample material to use, or the areas from which to sample for radiocarbon, as it is when used as supporting evidence for the Bayesian analysis of existing ^{14}C date sequences.

Hammerstone debitage as evidence for mining

In the continuing debate over the function of stone tools at mining sites (see Thomas, 2018, re Brandergang, Mitterberg), full analysis of total assemblages of hammerstone fragments is desirable, and if possible, this should be achieved through controlled excavation. One example of a hammerstone use-wear debitage assemblage (consisting of flakes and splinters) was collected from 1 cubic metre of mine spoil excavated from Trench 1 at the Penparc (West Cwmystwyth) Bronze Age mine (Figure 13). Most likely, this is the sort of typical assemblage of micro-flakes and splinters one can recover through sieving and careful excavation from the waste tips of some of these Early Bronze Age mines, yet formerly these fragments went un-noticed, thus they are rarely recorded within the literature on the subject. There is an added significance to all this. Such micro-debitage is usually found close to the workfaces where it is commonly associated with the firesetting debris and with layers of extraction/ development rock present in the mine spoil. This is very strong evidence therefore, that in these UK Bronze Age mines at least, most of the cobble stone tools were used for mining rock rather than for crushing ore. In fact, the type of tool debris recovered from the layers of finely broken-up rock and vein material associated with crushing platforms and processing pits is quite different to; so in terms of the number and weight of pieces identified, debitage from hand-held crushing tools is poorly represented. This is exactly the sort of test, which

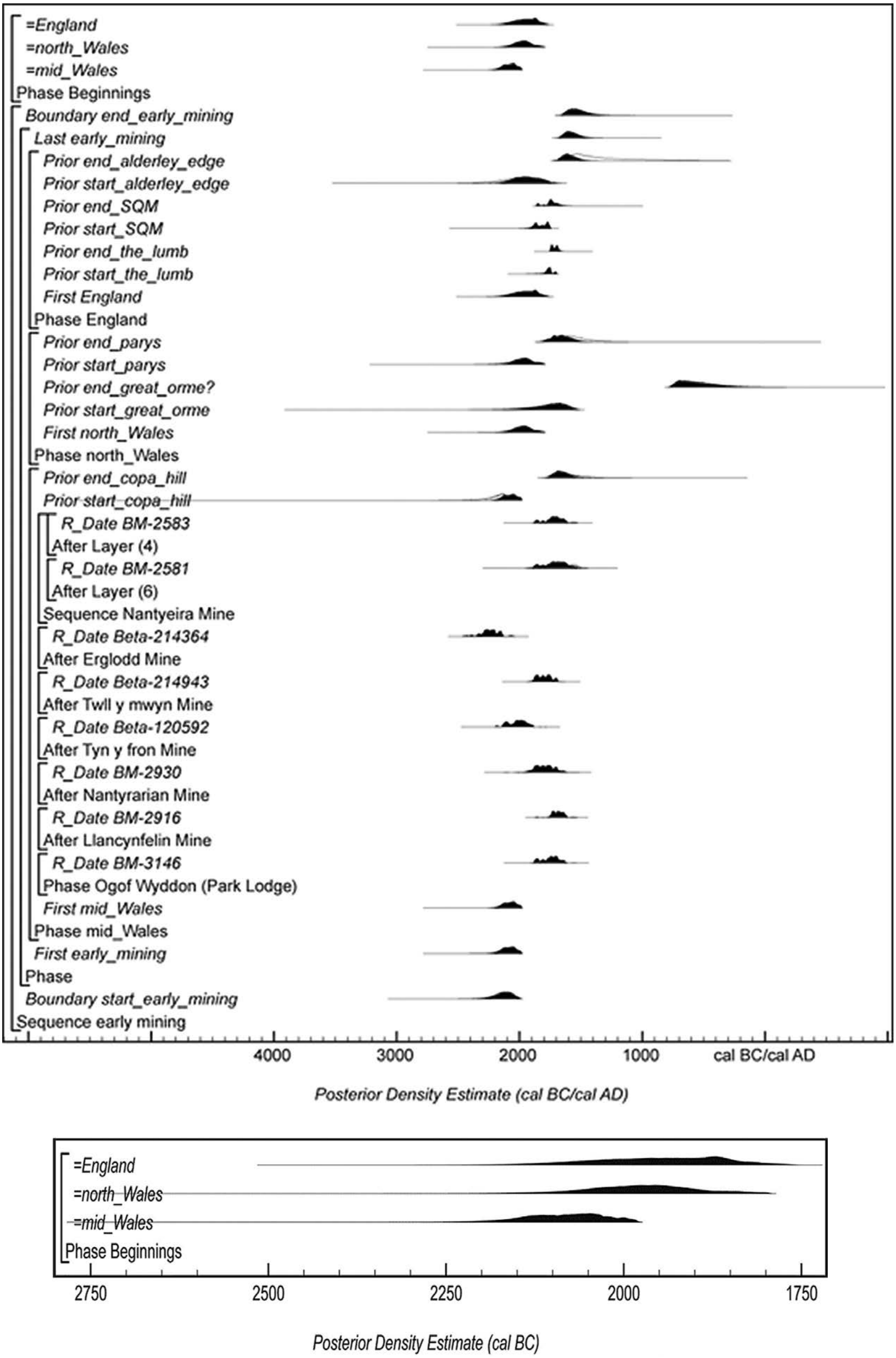


Figure 12. Bayesian-modelled ^{14}C date ranges for the British Bronze Age mines and a posterior density estimate of th geographical chronological shift in activity between Wales and England (Timberlake and Marshall, 2014).

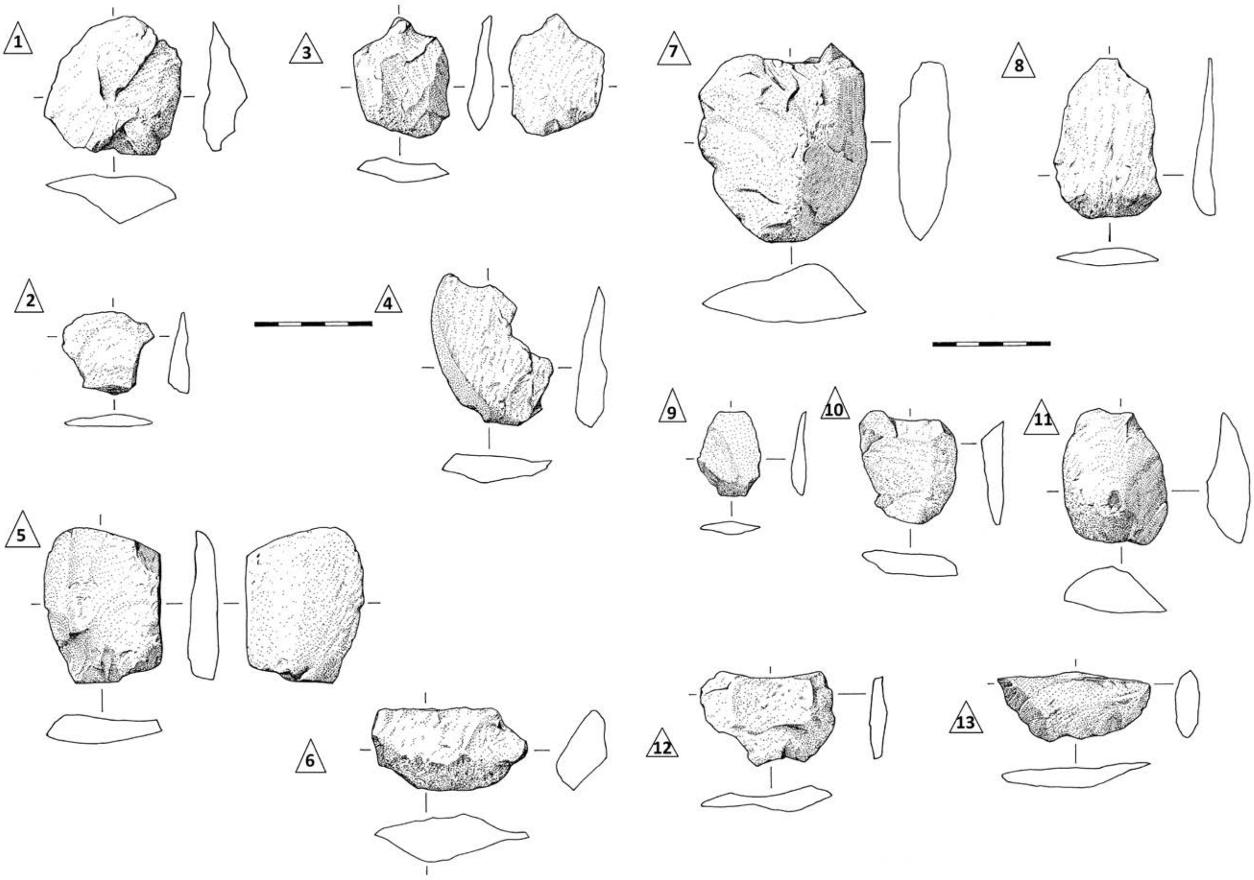


Figure 13. Hammerstone debitage (spalls and splinters) collected from minespoil at the Penparc (West Cwmystwyth) Bronze Age Mine. Drawing: B. Craddock.

should be applied at every early mining/ore processing site studied.

Evidence for the 'quarrying' and production of hammerstones at outcrop

The evidence for this is rare in Britain, but two examples have been encountered within the upper reaches of the River Severn catchment on the east side of Plynlimon in West Wales at the Nantyreira and Nantyricket prehistoric mines. The example shown here (Figure 14) is composed of a quartz-veined quartzitic greywacke fabricated from the local Ordovician (Van Formation) outcrop at Nantyreira. At this location the rock was being removed using the very same stone as the one being mined. This was achievable on account of the intense firing of the outcrop which took place during firesetting. The 'quarrying' of stone tools is quite unusual for Wales, yet it does resonate with the more ubiquitous evidence for the quarrying and fabrication of such tools elsewhere reported on by Alexander Maass in the Harz Mountains of Central Germany (Maass pers. com.) and at Cabrieres in SW France (Maass, 2005), as well as by Angela Celauro, Maass and Preto Gomes at Tras-os-Montes in Portugal (Maass and Celauro pers. com.).

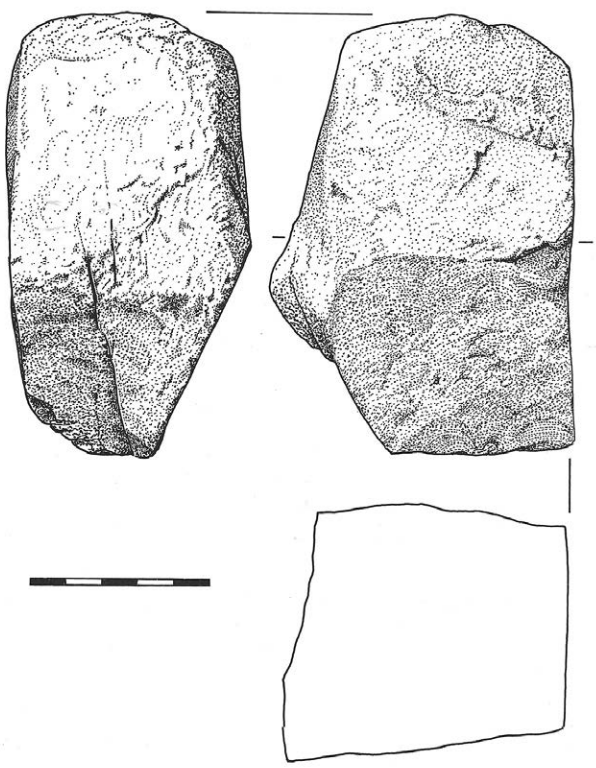


Figure 14. A hammerstone made from outcrop rock (quartzitic sandstone) quarried at or close to the Early Bronze Age copper mine of Nantyreira, Plynlimon. Drawing: B. Craddock.

Analysis

The recognition of mineral traces

The potential for the survival of ore mineral traces on the tips of mining tools and crushing stones and within the mortar hollows of anvils was investigated as part of an feasibility project undertaken at the University of Bangor, North Wales in the 1990s (Jenkins and Timberlake, 1997, pp.71-73). It had been noted that mineral staining, usually in the form of iron oxides, was sometimes associated with the crushing surfaces of small stone tools, as it was with the grinding and mortar hollows of ore processing stones, commonly referred to here as anvils. Yet assuming such residues did contain elevated amounts of copper/lead and zinc from the ore minerals worked, then the traces of these metals would have had to have survived the effects of washing, leaching and weathering, and at the same time remain distinguishable from the masking effect of heavy metals associated with the deposition of the surrounding iron/manganese oxides (iron pan horizon), or through the precipitation of copper and lead salts directly onto the stone surfaces. The only means therefore of linking these tools to the original ores worked would be to establish relative enhancements or depletions in metal upon the worked as opposed to the un-worked surfaces of these cobbles.

The examination of the surface of a dolerite anvil stone recovered from the Comet Lode Opencast excavations on Copa Hill (Cwmystwyth) was carried out using both SEM-EDXRA (Scanning Electron Microscope Energy Dispersive X-Ray Analysis) and pXRF (portable X-Ray Fluorescence). For example, two spots within an area of manganese/iron stain associated with the crushing surface of this tool were examined by SEM-EDXRA. The spectra showed a significantly enhanced lead content compared to the fresh rock underneath, and to the side of this. A pXRF scan of numerous points samples across the surface of the anvil was more interesting in that it showed greatly enhanced levels of lead and zinc, although this was in inverse proportion to the values expected; these being higher on the outside of the iron-stained area, than in the middle. Copper, on the other hand, was marginally elevated centrally (although the expected elemental background values for copper in the dolerite were still too high for this to be conclusive). The results of this preliminary work would seem to suggest some potential in these techniques for future investigation. However, whole artefact scanning of the surfaces of these tools for metals, such as copper and lead, may prove a more convincing method, providing a better indication of the actual ores worked. Some success in this approach was achieved at Alderley Edge examining the handle and working tip of a Bronze Age oak shovel recovered from the Brynlow Mine in 1874. The artefact was analysed at the Daresbury nuclear facility in 2011 using synchroton-based X-Ray Absorption Spectroscopy (XRAS) to measure the copper and arsenic chemical speciation across a 3-D surface (Smith, et al., 2011). This established beyond reasonable doubt that this tool had been used for the mining of copper ore.

Terminology

A word or two should be said about the terminology of stone tools. Most of us interested in the study of ancient mining will be aware that these tools are both rudimentary and universal – and by and large quite similar in form and a product of utilitarian need rather cultural design. Given their universal nature, it is perhaps surprising why there is so little standardisation in the sense of functional analysis and terminology. These tools (some of them with quite specific functions) are variously described in the literature as being: stone mining mauls, hammer stones, stone hammers, stone mallets, pounders, crushing stones, stone picks etc. – often with little or no clear knowledge of function. In order to refer to these in a more appropriate and relevant way it is proposed that these assemblages of stone tools are described using the generic and collective term 'cobble stone mining tools'; a term which more accurately reflects their origin as waterworn cobbles (or sometimes rounded weathered lumps of rock) selected for a range of interchangeable mining tool tasks. Only in one sense are all of these tools artefacts: all of them show signs of having been used, though only a few have actually been intentionally artefacted.

Recording

The tasks of object recording/illustration, functional analysis and experiment are closely linked in the process we have adopted for interpreting the use and significance of these toolsets. When dealing with large assemblages containing thousands of these cobble stone tools we have found it essential to develop some sort of simplified, analytical, yet quite standardised method of recording that can easily be undertaken in the field. With this in mind a standard two-page hammer stone recording sheet was developed by the Early Mines Research Group in the late 1990s (see Jenkins and Timberlake, 1997; Timberlake, 2003) (Figures 15a-c).

For each tool a combination of morphometric, petrological and wear-analysis data is measured and recorded to help determine a source for the cobble, any indication

STANDARD RECORD SHEET FOR HAMMER STONES

1: IDENTITY

Sample No.	Year	Sector	Context (Δ)

2: DIMENSIONS etc.

Weight (g)	Length x (cm)	Width y (cm)	Depth z (cm)

3: SHAPE etc.

Original shape	*Natural indentation*	*Roundness factor (1-9)*	*Surface (1-4) smoothness*	*Natural/modern abrasion*	*Hardness (3-8 mohs)*
Rectangular			Smooth (shore)	Glacial striae	3
Spherical		6	1	Beach attrition	4
Ovoid		7	2	Other	5
Pear		8	3		6
Cylindrical		9	4	Modern	7
Flattened			Rough	(accidental)	8

4: PETROLOGY

	Grain size	*Sorting*	*Banding*	*Grain roundness*	*Fels. %*	*Matrix cement*	*Structure*
Siltstone				0 (angular)			
Greywacke	Fine	v. well		1	<2		Joints
Sandstone	Medium	Well		2	2-5		Bedding
Arkose	Coarse	Moderate		3	5-10		Veins
Quartzite	v. coarse	Poor		4	10-25		Cleavage
Other	Pebbly			5	25-33		Other
				6 (spherical)	33-50		

5: COMPLETENESS

Small	<25%	Unused
Spall	25-40%	Pebble
	40-60%	
	60-75%	
	>75%	

6: TYPE OF FRACTURE

Conchoidal	Good	
	Medium	
	Poor	
Uneven		
Planar (Premature fracture)		

Figure 15a. Page 1 of the stone mining tool recording sheet developed and used by the EMRG in 1996.

of selection based upon shape, weight and cobble type, evidence of primary and secondary tool use, artefact modification and use wear history (the latter should include each conjectured recycling or discard event). One of the most important tasks in recording is accurate illustration. The standard required of a field illustration designed to accompany photographs is shown here, as recorded by Brenda Craddock (Figure 16). However, subtle details of modification or use-wear are best shown in fine ink drawings, many of which have since been reproduced in publication (see Figures 10-11).

Two case studies of stone mining tools

Two tool assemblages from British mines (Cwmystwyth and Ecton) have been examined here in slightly more detail.

Copa Hill, Cwmystwyth

Cobble stone mining tools have been studied at the Bronze Age mine on Copa Hill and the following details recorded. At least 79 % of the cobbles brought to

7: WEAR ANALYSIS – 1 Hammering

End wear				Edge wear		Side wear	
Single ended (1)		Double ended (2)					
Primary	*secondary*	*Primary*	*secondary*	*Primary*	*secondary*	*primary*	*secondary*
Bruising				Bruising		Slight bruising	
Slight pounding						Bruising	
Moderate pounding						Indentation	
Heavy pounding				Heavy pounding	Heavy pounding		
Flaking							
Heavy flaking							
Faceted area				Faceted area		Faceted area	
Mineral residue		Mineral residue		Mineral residue		Mineral residue	

7.2 Grinding	7.3 Crushing anvil use		7.4 Re-use as flake
Location	*Primary*	*Secondary*	
Faint	Slight bruising		Hammering end
	Strong bruising		Chisel end
Strong	Indentation		
			Degree of use
Grinding marks – striations	Location		Slight
	Flake surface		Moderate
Faceted area/	Pebble surface		Heavy
Mineral residue	Mineral residue		Scratch markings

8: MODIFICATION (for hafting/handgrip)

Position	*Primary*				*Secondary*				
mid girth	Edges	Side	Semi-continuous	groove	Edges	side	Use of Natural indentat-ion in Pebble	Contem-porary scratch/ Scoring	Evidence for haft wear?
Towards narrow end	Scratch notching				Rounded sharp edge of Flake				
Towards broad end								certain	
Centre of gravity					Notching			Possible	

9: SUMMARY DESCRIPTION OF TOOL (Estimate)

- well used
- poorly used
- long survival of usefulness

- hammering
- crushing
- small hammer for other tool
- anvil stone

- re-used

- recommend for detailed drawing
- recommend retain collection

10: PHOTOGRAPHS
(3 views: digital or print)

11: DRAWINGS
(annotated field drawings with outline 1:1 profiles: longitud. and transverse)

Figure 15b: Page 2 of EMRG stone mining tool recording sheet (as above).

HAMMER-STONE DATA RECORD KEY:

COBBLE SHAPE: spherical=1; pear=2; ovoid=3; cylindrical=4; rectangular=5; flattened=6

COBBLE ROUNDNESS (1 to 9): factor 6 (slight irreg) - 9 (v round)

COBBLE SMOOTHNESS (1 to 6): 1 (v smooth = beach pebble) - 6 (rough)

SURFACE ABRASION: GS=glacial striae; BA=beach attrition; M=modern (accidental etc)

HARDNESS: Moh's hardness scale 2 (soft) - 8 (v hard) NB vein quartz = 7-7.5

PETROLOGY (rock type): A= mudstone/siltstone; B= laminated fine grained flaggy sandstone; C =fine grained felspathic grit/greywacke; Ca = more felspathic type; Cc=micaceous greywacke/bedded flagstone; Cb= quartzitic greywacke; D = quartzitic grit; E= quartzite; F= exotic(glacial erratic cobble - incl non-local quatzites and igneous rocks eg. dolerites, qtz porphyry)
Identified types of all cobbles include: Types C, Cb, Cc, Ca, D, Cc/Cb, Cb/D, Ca/Cc,Ca/Cb, Ca/D, Cc/D, A, B, E, F

GRAIN SIZE (1-5): 1(Fine grained) - 5 (small pebbly clasts)

GRAIN ROUNDNESS FACTOR (1to 6): 1(angular) - 5 (nr spherical/well rounded grains)

FELDSPAR CONTENT: % of felspar from <5% - >75% (white grains of detrital plagioclase or orthoclase)

STRUCTURE: J=joints; B=bedding; QV = quartz vein; CL=cleavage

COMPLETENESS = % of cobble surviving, either as core or flake/spall

TYPE OF FRACTURE: C=conchoidal; U=uneven; PL=planar (usually premature fracture along joint plane or qtz vein

FRACTURE SCALE: 1=premature(planar)fracture; 2=uneven; 3=poor conchoidal; 4=medium conchoidal; 5= good conchoidal

WEAR ANALYSIS: END WEAR: x2=double ended; primary + 2ndry = use/re-use; 1=bruising; 2=slight pounding; 3=moderate pounding; 4=heavy pounding; 5=flaking; 6=heavy flaking (similar scale with EDGE WEAR & SIDE WEAR. FACET: x1 or x2 etc facets or surfaces worn flat from wear

CRUSHING ANVIL USE: flk= location on flake or fracture surface; pbl = location of use on natural pebble surface; 1=slight bruising; 2= strong bruising; 3=indentation

RE-USE AS FLAKE TOOL: H=hammering use; CH=chisel/pick use; 1=slight use; 2=moderate use; 3=heavy

MODIFICATION OF COBBLE (HAFTING): POSITION: A=mid-girth; B=towards narrow end; C=towards broad end; D=centre of gravity;
TYPE OF MODIFICATION: 1=scratch notching; 2=edge notches in cobble; 3=side notch/indentation; 4=semi-continuous groove; A= secondary notching of edges; B=rounded off sharp edges of flake; C= 2ndry notching; D=2ndry side notch

HAMMER TYPE CLASSIFICATION: **1A**= unmodified single end use as hammer; **1Aa**=double end use (1 end >); **1B**=use of side pebble as hammer for crushing/or as mallet; **1C**=broken tip of hammer (or small pebble) re-used as hand-held crushing/pounding tool around edges; **1D**= flake tool re-use (as chisel etc); **1E**= use/re-use of cobble surface as anvil stone (for crushing); **1F**= pecking stone for notching (typically lump quartz)

2A = modified (notched for hafting) single end hammer; **2Aa** = ...double end hammer;
2AE = modified end hammer/anvil stone; **3A** = further modified hammer(semi-grooved for hafting) ...etc

Figure 15c. Page 3 of EMRG stone mining tool recording sheet (the hammerstone information and data record key).

this site for use as hammerstones had degrees of polish/smoothness similar to beach (littoral) pebbles, whilst 36 % had roundness indices exceeding those of local river (fluvial) pebbles (Gale, 1995). The average weight for near-complete examples of cobble stone hammers found within the mine was between 2-2.25 kg, whilst for the larger fragments found outside of the mine upon the tips it was less (i.e. between 1-2 kg). In fact, most of the cobbles were 15-25 cm long and 8-13 cm wide, and were cylindrical to flat-sided, suggesting a moderate amount of size and shape selection at source. Similarly, there appeared to be some selection of the finer grained and generally harder rocks amongst the greywacke cobbles; in fact, 42 % of these greywackes were composed of quartz-cemented sandstones (see Figure 10). Nevertheless, there was no evidence to suggest any sort of vigilant selection to eliminate potentially flawed cobbles – although this might just reflect the difficulties in detecting incipient joints within a well-rounded stone.

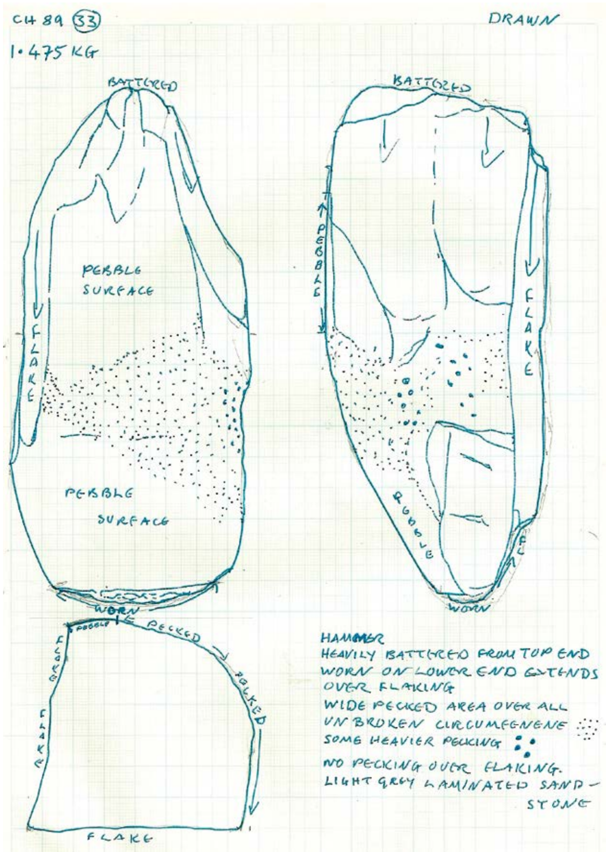


Figure 16: Measured field drawing of cobble stone tool CH 89 33 from Copa Hill, Cwmystwyth. Length 170 mm. Pencil and ink drawing: B. Craddock.

A survey of potential cobble sources within the Ystwyth Valley was then undertaken out over the 25 km stretch of valley, which lay between the mine and the sea. The results of this indicated a 'best match' with pebbles taken from the storm beach shingle bars located near the mouth of the River Ystwyth (Jenkins and Timberlake, 1997). This probable source was determined by measuring three different parameters: (1) the amount of 'flattening' of the pebbles, (2) the degree of smoothness/ polish of the surface, and (3) the presence or absence of beach pebble attrition (or 'chatter') marks. Natural selection of pebbles on a storm beach ensures that hard, competent, flawless cobbles predominate. From amongst these, the more cylindrical-shaped pebbles were preferentially chosen. By contrast, unworn glacial erratic cobbles collected from inland sources near to the mine were rarely found used as tools, alongside less than 30 % of 'good fit' re-worked river pebbles.

Some 99 % of the cobbles used as tools were composed of greywacke sandstones - all of them geologically local to this area of mid-Wales. However, most of the beach pebble sources contained at least 5 % of igneous and metamorphic rocks from North Wales, the Lake District and Scotland, the latter brought to this coast as glacial erratics by the Irish Sea Ice. Although hard and heavy enough for use as tool material, these 'exotics' were only rarely found as hammers – most likely because on account of their rarity as suitably sized and shaped cobbles. In general, therefore, lithology seems to be of secondary importance to cobble shape, size and weight. Nevertheless, some 66 % of the hammers used (or re-used) as anvils were composed of the harder quartzitic sandstones and coarser grain size lithologies.

Tool functions represented amongst the used cobbles were assessed in the following proportions. The largest group (67 %) consisted of the actual mining tools themselves (rock-breaking hammers), with the crushing anvils (used or re-used) at 13 %, mallets or chisels 8 %, hand-held crushing tools 6 %, and re-used flake tools 6 %. Meanwhile the study of 1203 cobble stone tools revealed that only 9 % showed indisputable evidence of modification for the purpose of hafting (this included 75 edge-notched hammers but only 4 semi-grooved examples). Meanwhile 41 % of tools appear to have been re-used following initial breakage – some of them at least 3 or 4 times!

Ecton Hill, Staffordshire

The tools from this mine provide a useful contrast with those from recorded from Copa Hill. Cobble stone tools from this site are altogether less frequent, with the great majority, even the rock-breaking hammerstones, being hand-held implements. In terms of tool types common to other sites, only the disc-shaped cobles used for crushing (Type C3) share similarities with those found at Alderley Edge, and to a lesser extent with some of the west Wales mines. In fact, Ecton is unique for the small and unsophisticated nature of its toolset, most of which have probably had a very short span of use. Somewhat surprisingly, given the proximity of the mine to Alderley Edge, there are no examples of grooved tools. Instead we see a new category of implement, the pointed pebble or pestle (Type C4) which may have been used as a small hammer to crush the mineral (such as copper carbonate) adhering to the outcrop (Figure 17). Despite these differences, we still find that 35 % of the tools show evidence for multiple function and re-use.

The geological origin of the two main types of cobble used as mining tools at Ecton is interesting, since both can be matched with identifiable sources (see Timberlake, 2014). Indeed most of the rounded-rectangular patinated river cobbles of quartzitic-sandstone, gritstone, and siltstone found upon the tips of the mine can still be

Figure 17. Pointed pebble or pestle tool (Type C4) from Ecton, Staffordshire. Length approximately 160 mm. Photo: S. Timberlake.

collected from the river bed and flood plain of the River Manifold between Hulme End and Ecton Hill. These cobbles make up 75 % of the stone tools found at Stone Quarry and The Lumb mines. Most will have been derived from the erosion of individual sandstone and proto-quartzite sandstone units (such as The Minn, Hardlow, Lum Edge, and Longnor Sandstones) within the Upper Carboniferous Edale Shale Group; the outcrops of which have been eroded away by the incision of the river less than 2 km upstream of the mine (Ford, 2000, p.2 and 6). The second type of cobble used for mining tools is a metaquartzite, examples of which can be collected a little further afield. All of the latter have origins as glacial erratics; significant numbers of which appear to be associated with Neogene sand pockets infilling solution features and other erosional features within the Carboniferous Limestone. The nearest significant sand pocket and source of glacial erratics to Ecton lies a few kilometres to the north and west of the nearby village of Hulme End. Given that there is no evidence that any of these ended up as river cobbles in the River Manifold, the most likely explanation is that all of these stones were collected at source from the weathered surface of the limestone.

Tool function and type

Tool types reflecting the utilitarian nature and interchangeable functions of the mining and beneficiation process have been found at all of the prehistoric mines investigated. Whilst these do vary slightly from mine to mine, the tool functions they represent are universally relevant (Timberlake and Craddock, 2013). However, it would be quite unwise to consider these as anything other than a continuum of forms. For instance, it would be possible in some cases to classify the same cobble as two completely different tool types. Nevertheless, the formal classification is most likely to reflect its primary function, as suggested by shape and dominant use-wear characteristics.

Single and double-ended (ungrooved) mining hammers (Types A and AA)
These are un-modified (Figure 10) or slightly modified (notched) elongate cobbles (Figure 11) used primarily as rock-breaking tools (Figure 18). Some of these appear to have been hafted (see Figure 18), whilst others (for example most of the Ecton hammerstones) would probably have been hand-held (Figure 18c). The double-ended hammers may have been used at alternate ends for picking or for smashing rock, for heavy pounding, or as mallets for use with other tools (Figure 18 d, e). It now seems that most of these tools were hafted given recent experimental reconstructions (Timberlake, 2007).

Grooved mining hammers (Types 2A & 3A).
The prehistoric mines of Alderley Edge are unique in Britain given that some 93 % of the cobble stone mining tools show clear evidence for haft modification (either as notched, partially grooved (Type 2) or fully-grooved (Type 3) forms) (see Figure 9). Note type 2+3 are similar to Types A and AA in terms of the morphology of their use, except that these have been intentionally modified with the addition of full or partial grooves for the attachment of handles. Grooved hammerstones are also found within the mines of Ross Island, Killarney, SW Ireland. Some of the Alderley Edge hammers show extensive haft-wear around the median groove, thus occasionally we see the insertion of an additional butt-end groove over the broader top end. Butt-end grooves and additional lateral grooves were probably inserted as a response to wear-related movement in the haftings, and perhaps also because of problems with the geometry of the cobble(s), such as when the narrower 'pick' end of the tool was used. The cobble source for the Alderley Edge hammers appears mainly to be the local glacial drift (boulder clay) with its large number of erratic rocks from the Lake District and Northern England. Most of the cobbles used appear to be composed of hard greywacke types, such as those which outcrop to the east and south of the Lakes, although there are granitic rocks such as the Shap Granite and Ennerdale Granophyre (see Figure 9) and large numbers of utilised cobbles of andesite, basalt and tuff derived from the Borrowdale Volcanic Series (Browne, 1995). Re-cycling was also observed – though to a less degree than at most

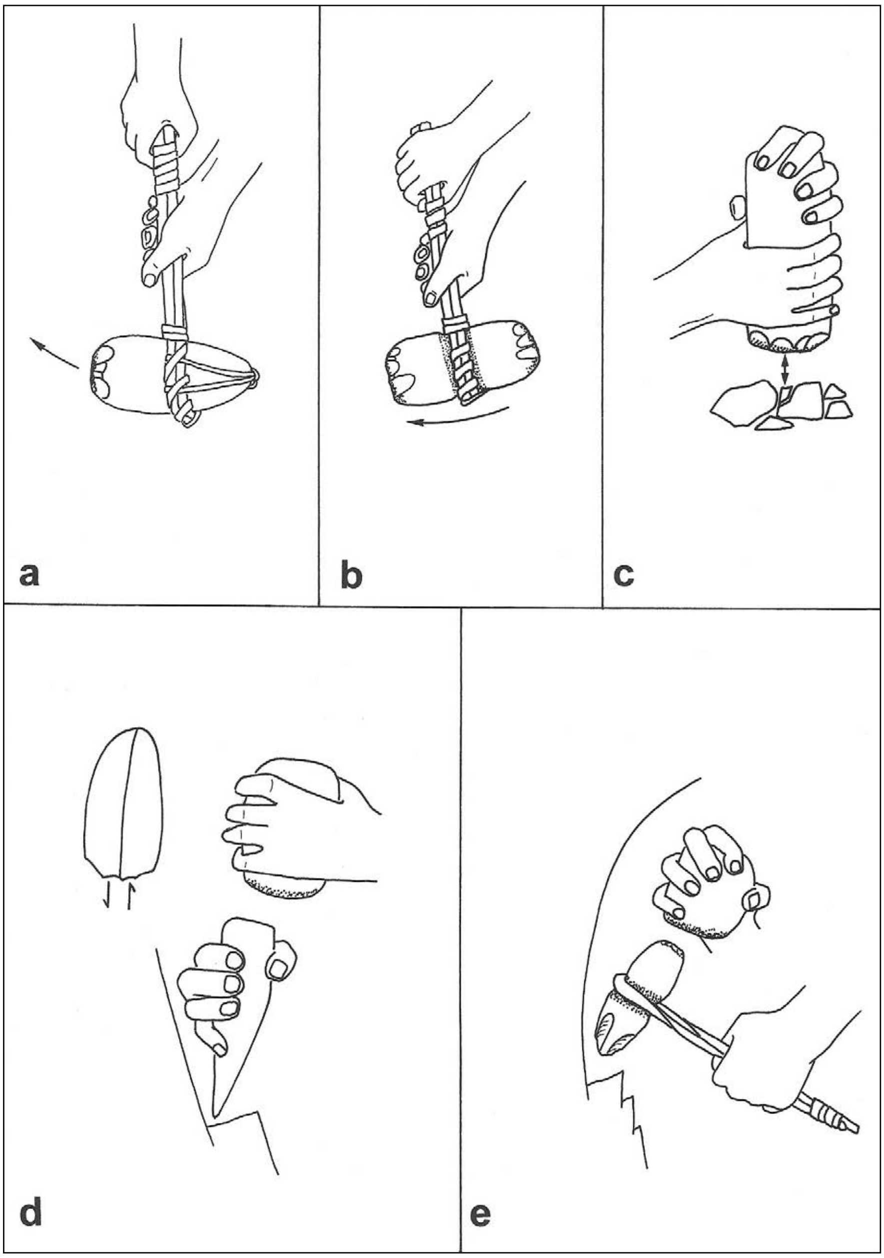


Figure 18. The use of cobble stone tools: (a) mining hammer Type A; (b) mining hammer Type AA; (c) crushing implement Type C; (d) + (e) picks and chisels Type D. Drawings: B. Craddock.

of the upland Welsh mines. It seems possible that these cobbles were grooved because they survived for much longer without fracturing when used against the marginally softer sandstone rocks (such as those of the Engine Vein Conglomerate and Wilmslow Sandstone), but perhaps also because the procurement of suitably sized and shaped (rounded) cobbles was a little more difficult.

Picks or chisels (Type D)
These tools were used for levering-off rock and for small extraction work and were commonly found modified (notched) and re-used. Typically, the cobble edges of these had already been removed through use; some of these were re-used flakes detached from hammers, but others were remnant cores. Most were probably held in a short haft and used with or without a mallet (Figure 18e). Where such flakes have been re-used as small chisels or wedges (see Figure 18d), they can generally be recognised as such from the rounding of the fracture surface.

Pecking stones (Type F)
Rarely found, these weren't mining tools, but instead were used for notching the hammerstone cobbles (Figure 19d). The few examples that have been found were small (5-8 cms diameter), round, and hard – often as vein quartz or quartzite pebbles.

Crushing tools (Type C)
Most of these hand-held tools (8-20 cms long) appear to have been used for breaking-up the ore and then fine-crushing the mineral. Frequent amongst these were the broken-off ends of mining hammers re-used as crushing stones (Figure 19a). Another common variant of this type (Type C3) was the small cobble worked around its

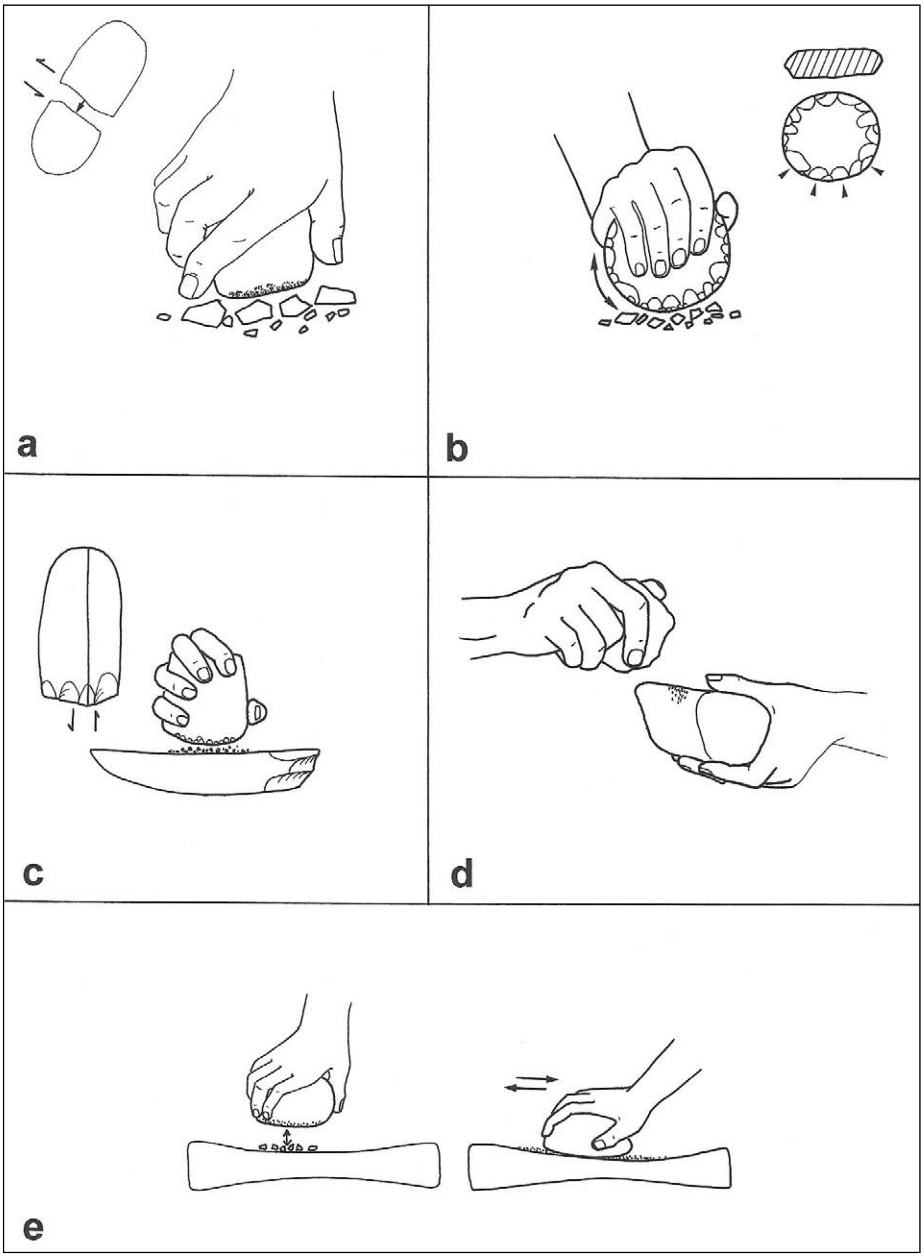


Figure 19. The use of cobble stone tools: (a) + (b) crushing implements C1+C3; (c) anvil stone E; (d) pecking stone (Type F); (e) a 'saddlequern-type' grindstone (Type G). Drawings: B. Craddock.

outer edge (Timberlake, 2005a; 2006). On account of how these were held and worked, they often ended up being discoid in shape (see Figure 19). Sometimes larger cylindrical-shaped cobble hammerstones (up to 1.5 kg in weight) were also used as hand-held crushing implements (Figure 19c).

Crushing anvils (Type E)
Anvils were used for crushing small pieces of ore (see Figure 19c). Depending upon the degree of use and type of work carried out, these anvil stones might appear flat with worked surface(s), or else have slightly indented (mortar) impressions upon them (Figure 20). In fact, more than 50 % of the cobbles used as anvils were just fractured and split mining hammers re-used either upon their flattest sides or split fracture surfaces for ore crushing. However, where we find flat cobbles chosen at source for this use, we do see some selection of the coarser sandstone greywacke lithologies.

Grinding stone (Type G)
Invariably this would be a larger stone slab used like a saddlequern for the fine grinding of an ore mineral mix, or for the grinding of a smelting slag to release the entrapped metal prills (see Figure 19d). These are very rare finds indeed; just single examples coming from Copa Hill (Timberlake, 2003, Fig.96, D) and another from Ross Island, Killarney (O'Brien, 2004, p.359).

Boulder battering stone (Type L)
Inevitably these are large utilised cobbles (usually > 8 kg in weight) used as a rock-battering implements. One suggested method of use would be to sling such a boulder from a rope on a tripod and then swing it against

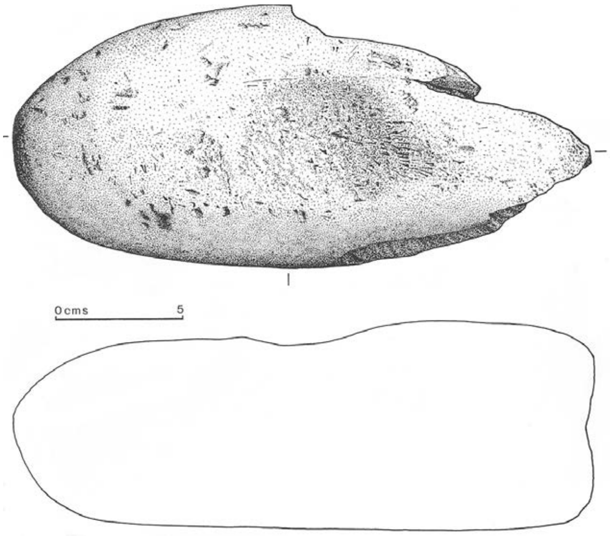


Figure 20. A crushing anvil (Type E) from Copa Hill. In fact, this is a recycled mining hammer used on its side; weight 2.25 kg. Drawing: B. Craddock.

the rock face. The effectiveness of this arrangement was aptly demonstrated during experiments carried out on the Great Orme in 1989. Quite a few large cobbles or boulders of this size have been found used as 'hammers' within the Orme prehistoric mine (Lewis, 1990, p.5). Another was found at Alderley Edge (Timberlake, 2005a, p.69, Fig.5. 6).

Figure 21. Experimental hafting of a cobble tool in preparation for mining experiments at Sakdisi, Georgia. Photo: S. Timberlake.

Experimental archaeology

The making and use of stone mining tools

One of the most interesting aspects of this work has been the undertaking of archaeological experiments – for example, the manufacture and use of hafted cobble stone mining hammers (Craddock, et al., 2003; Timberlake, 2007). In 1997, Brenda Craddock of the EMRG led a workshop in the making and using of grooved stone tools at an open day held by the National Trust at Alderley Edge.

Using a small quartz pecking stone, a groove 2-10 mm deep and 15-20 mm wide excavated around the median circumference of a 100 mm diameter greywacke cobble in just under an hour (Timberlake and Craddock, 2005). In retrospect, what we found following the hafting and use of this cobble was that it really wasn't necessary to peck much of a groove on the flat cobble surfaces. We found the same thing on some of the archaeological examples. Making the handle for the tool involved bruising and twisting a hazel withy (approximately 1.2 m long), then bending and tying this around a cobble and binding it with rawhide (Figure 21). In our attempts to reconstruct the Alderley Edge mining tools, similar cobbles to those we find archaeologically were collected from the local Boulder Clay deposits. Archaeological experiments such as this can help us to understand the manufacture, function, and use-wear that we find upon artefacts. They can also be used to predict archaeological findings.

Our first experiments using these tools in conjunction with ropes and leather bindings were carried out in 1988 and 1989 at our Penguelan experimental site at Cwmystwyth where previously we had been firesetting on the vein (see Pickin and Timberlake, 1988; Timberlake, 1990b). Later we tried using hammers hafted with freshly-cut green willow handles (Craddock, 1990). These proved to be rather too flexible, which made it difficult to accurately direct the tools against the rock. Following this, completely unmodified or just lightly notched (but un-grooved) cobble stone mining hammers were experimented with using a hafting method modelled on the 'Chuquicamata-type' (Craddock, et al., 2003). The latter was an intact tool discovered in 1900 accompanying the mummified remains of a pre-Columbian copper miner found at the Restoraurada Mine, Chuquicamata in Northern Chile (Bird, 1979) (Figure 22). These recon-

Figure 22. A mining hammer with its hafting from Chuquicamata, Chile. Photo: courtesy of The British Museum and W. Wray (1995) see also Timberlake and Craddock (2013).

structions of ours were more successful; one of them removing 1.5 tons of rock without any serious breakage of the cobble.

It was noted that very little breakage of these river or beach cobble hammers occurred whilst they were being used against the already fire-weakened rock. Instead, the characteristic flaking or splitting of the ends of these cobbles began *only* once the zone of rock unaffected by fire-setting had been reached. Inevitably, the miners would have continued to try to use their tools against this until the rate of breakage and difficulty of progress prompted them to stop and re-fireset the face. Most likely therefore the batter or pounding marks that we find preserved on some areas of the rock quite simply reflects the practical limit of mining reached during the last fire-setting operation. This was proved experimentally, but then later recognized within the roof of the small Bronze Age mine gallery on Copa Hill during excavations carried out in 1989-1990 (Figure 23).

The wear facets and flaked/ fractured surfaces produced on these cobbles as a result of their experimental use as hammers have since been examined with an eye to recognizing the same type of wear amongst the tools recovered from the mines. During these experiments, we noted that we had scratched or pecked rather similar types of bi-lateral notches into the sides of these cobbles whilst attempting to haft and re-haft them using withy

Figure 23. The roof of a prehistoric mine gallery within the Copa Hill Bronze Age Mine worked using stone tools. Photo: S. Timberlake.

handles. We also noted rather similar impressions on the hammer stones when we tried using/ re-using them as ore-crushing anvils. However, these were not quite so developed as the examples we found in the mines.

In 1997 we experimented with fully-grooved cobble stone mining hammers at Alderley Edge, using these tools against previously fireset sandstones and conglomerates (Timberlake, 2005b). Not surprisingly, the haftings appeared to hold slightly better on these tools than on the completely unmodified cobbles. More important though was to remember to use these tools in the right way; swinging them underarm against the rock face, using the weight and momentum of the hammer (as well as the bounce of its return) to help loosen joints and cleavage planes, including those previously weakened by firesetting.

It was soon realized that repairing the broken hammer hafts and re-tightening the bindings where these had worked loose was an essential, though necessarily repetitive part of the mining process (Timberlake and Craddock, 2005). In fact we estimated that somebody would be needed every half hour or so to repair the tools, and as a result, somebody with these skills would have been an essential member of any mining team.

The most recent mining experiments carried out using these tools was undertaken at Sakdrisi, mine in Georgia, in 2011 and 2013 (Stöllner, et al., 2012) (Figure 24).

Figure 24. A prehistoric mining experiment carried out at the Sakdrisi mine in Georgia in 2011. Photo: S. Timberlake.

Firesetting experiments

The first firesetting experiment we conducted was undertaken at Cwmystwyth in 1987, and since then the site has been used on more than eight different occasions (Timberlake, 1990b; 2005b, p.188). Over this period, the size of the firewood pieces used has decreased from 3 m to 0.5 m split logs, at the same time we began introducing larger amounts of thinner and faster-burning branchwood. This seemed to match the archaeological evidence, which suggested the use of smaller hearths and oak branchwood as a fuel for firesetting within the prehistoric mine (Nayling in Timberlake, 2003).

Typically, between 100-250 kilos of firewood was used in each of our experimental firings, and by the end of this period the wood fuel: stone extraction ratio had improved substantially from 1:1 to 1:2. This reflected an increase in skill, a more economic use of the fuel available, and a much better understanding of the properties of the rock.

Experimentation has provided us with at least one important realization; that dousing the hot rock with water is unnecessary in most cases. Whilst 'quenching' might help to shatter the rock surface, this practice did not significantly increase the yield of rock extracted. However, two interesting sets of reactions were observed when firesetting these shale and quartz veined rocks: firstly a decrepitation of the slate brought about by thermal shock as the temperature of the rock-face rose rapidly to 800°C, explosively ejecting debris (< 0.01 % of the total mass of extracted); and secondly, the splitting open of joints/cleavage by steam as water already present within the pervious rock vapourised and expanded. The latter could lead in some cases to the collapse of sections of rock during firing, but more typically, it would leave the rockface much-weakened, allowing for its easy removal in large blocks using stone, wood and antler tools.

The area of maximum heat penetration of the rock, as suggested by the changed profile of the rock face after mining with stone tools for several hours, was approximately 0.5 to 1 metre above the level of the hearth floor. The result was a prominent rock step or 'heel' left at the base of the fired face. Likewise, the types of concavities formed remain one of the most distinctive signatures of firesetting (Timberlake, 2003). Though less evident in shale rocks than in the granular sandstones and limestones, a rather good example of a hearth step, alongside the characteristic arched profile of firesetting was observed within the small Bronze Age mine gallery found within the mine on Copa Hill (see Figure 23). Yet in other places, perhaps using different techniques, Bronze Age miners have managed to sink shafts or vertical trenches into their mines with nothing more than fire and stone tools. We can witness a number of more complex shafts and galleries of this kind within the mines of Kestel, Turkey (Willies, 1990), Zawar in Rajasthan (Willies, 1987), and Sakdrisi in Georgia (Stöllner, Gambaschidze and Hauptmann, 2008). In fact, the most recent experiments at Penguelan, Cwmystwyth have shown how the use of smaller fires covered by heavy wood or stone to reduce air-flow, not only improves fuel efficiency, but also slows down the burn, thereby helping to direct the heat penetration downwards.

The most recent firesetting and mining experiments carried out at Sakdrissi Mine in Georgia (Stöllner, et al., 2012) have proven the use of this technique in breaking-up some of the hardest rocks imaginable – in this case silicified rhyodacitic volcanics. In 2011 and 2013 repeated firesets were carried out by the author using dried brush scrub and cut seasoned oak firewood against a series of quartz-hematite veins exposed within the side of a mining road upon the edge of the ancient mine (Figure 25). At its most efficient, 255 kg of wood was burnt (and the hot rock doused with a small amount of water at the end of 2 hours) to give 279 kg of rock, this being removed with the aid of hafted cobble stone tools and antler picks. Such results may be usefully compared with the experiments of Ancel and Py (2008).

Processing ores

Ore recovery in Bronze Age Britain often depended on the careful hand-picking of an enriched ore composed mostly of secondary (usually oxidised) copper minerals intimately mixed within a gangue of quartz and goethite. The hand-picking of mineral followed the crushing of selected ore lumps, resulting in a concentrate sufficiently rich enough for simple reduction smelting within a crucible or small-scale hole-in-the-ground furnace. Processing tools then would probably just have consisted of stone anvils and crushing stones, a grinding stone, and bone or wooden spatulas for the separation of grains; a concentration mechanism which may have been assisted, in some cases, by the use of a wooden launder and a flow of water for cleaning and gravity separation. One example of a 5m long split and hollowed-out alder log launder, probably used for mine drainage as well as for mineral recovery was excavated inside of the rock-cut entrance to the Bronze Age opencast on Copa Hill between 1993 and 1996 (see Figure 4). Skilled use of this

Figure 25. Firesetting on two parallel vein workings at Sakdrisi, Georgia in 2013 note the temperature probe for the firings can be seen against the rock face on the RH szide. Photo: S. Timberlake.

simple piece of equipment may have facilitated the separation of crushed gangue from ore, as well as the separation of the heavier lead minerals from the copper, and the chalcopyrite from the slightly lighter copper carbonates and oxides. The latter could however have been a colour/ textural separation assisted by water.

At Cwmystwyth the relatively small extractable pockets of oxidised chalcopyrite vein material mined from the top of the vein may have contained up to 30 % copper in the form of copper carbonates alongside copper present in the form of an as yet unidentifiable mix associated with goethite (see for example Williams, 2023, pp.141-142 for a comparable oxidised ore from the Great Orme). The Copa Hill Comet Lode outcrop ore could have made up just 1-2 % of the total rock extracted, which when coupled with a minimum recovery rate of 30-40 % after hand-picking, crushing, washing and sorting followed by smelting, meant that the actual metal yield would probably now be seen as uneconomic (in historical terms). Nevertheless, this seems to have been worthwhile at a time when locally-sourced metal was rare, thus valuable in small amounts.

An example of this scarce yet sample-rich easily-smeltable mineral ore sifted out and collected from amongst all the crushed veinstuff was identified on Copa Hill (Timberlake and Marshall, 2013, pp.79-80) (Figure 26). This particular piece was collected from the fine-crushed fraction sampled from within the ancient tips, and is a rare survival. This scarcity attests to the thoroughness of the prehistoric miner's 'total extraction'. The comprehensively executed nature of this mining is perhaps the very reason why these ancient mine workings survived the more intensive historic exploitation

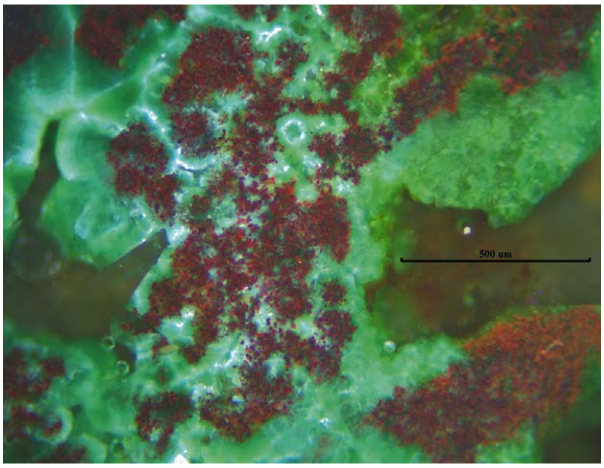


Figure 26. Microscope image of copper ore sample from the Bronze Age Mine on Copa Hill, Cwmystwyth - includes malachite, cuprite and native copper. Scale 500 nm. Photographed under plane polarised light: photo by courtesy of A. Williams.

of the site. All of the later mining was focused upon the richer sulphide ores (predominantly galena) left within the un-exploited veins beneath the ancient mine. These were mined from below, from adits and shafts driven into the side of the hill. Today this ancient mine looks to be completely sterile of copper, but appearances belie the evidence of chemical analyses which prove beyond doubt the ubiquity of this metal, much of which now lies invisibly fixed within the extensive iron pan and crushed mining sediment layers infilling the prehistoric working (Jenkins and Timberlake, 1997).

The gravity separation of copper and lead minerals using water in the manner implied by the find of the launders has not been tested experimentally at Cwmystwyth, although the actual crushing and milling of the hand-picked ores has, and in this case has produced a smeltable concentrate. Elsewhere some useful experiments involving the crushing and separation of iron oxides from gangue, followed by the washing-out and gravity separation of gold particles were undertaken by the author during the joint Deutsches Bergbau-Museum Bochum (DBM) and National Museum of Georgia expedition to Sakdrisi in 2011 and 2013.

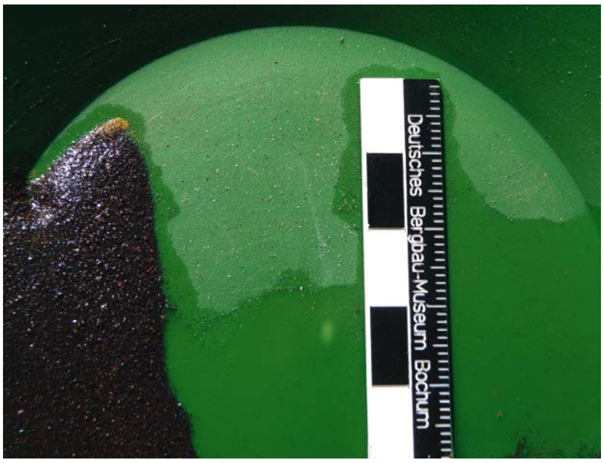
At Sakdrisi all of the potential gold-bearing rock mined was first separated out from the rock waste, the hematite : quartz : waste rock ratio ranging from 1:2:3 to 1:3:2 (by weight). The iron gossan-bearing quartz was then crushed on anvil stones, and then milled inside of the hollows on the mortar stones using small pounding

Figure 27. Grinding quartz-hematite to powder prior to gold washing at Sakdrisi in 2013. Photo: S. Timberlake.

stones or flat-sided crushers, the goal being the reduction of this to a grit-size consistency (2-3 mm). Parcels of this crushed ore were next fine-ground to a powder upon large 'saddle-quern type' grinding stones using suitably flat or slightly convex-worn rubbing stones (Figure 27). Our subsequent washings of these residues showed that a grain size of between 0.25-0.5 mm was probably the best fraction for gold recovery. The samples of pulverised ore weighing between 0.5-1 kg were panned using water raised by bucket from an anciently-cut rock cistern perched on the edge of the adjacent opencast. Pan washing these samples for 10-15 minutes removed the quartz and produced a dark concentrate of hematite. This was much harder to pan away, yet a number of the samples with significant hematite and goethite contents (30-40 % $Fe_2 0_3$ + FeO.(OH)) yielded some of the best heads of gold – the latter composed of fine yellow flakes, the largest of these grains being only 0.5 mm in diameter (Figure 28).

The above experiments provided a very useful lesson on how it was possible to use a basic technology to help gravity-separate mixtures of different minerals with variable and sometimes just small degrees of difference in specific gravity. The processors of tin-hematite ores at the Early Bronze Age mining settlement of Kestel-Goltepe in the Taurus Mountains of Turkey (Yener, et al., 2003) were faced with a similar problem, and managed to achieve a good result from what we would now consider to be relatively low-grade material. In a slightly different way, the Middle Bronze Age ore dressers at the Troiboden processing site on the Mitterberg seem to have perfected a way of separating the crushed sulphide ore from the gangue, and perhaps the pyrite from the chalcopyrite through the control of flowing water and agitation of the ore slurry within wooden tanks – perhaps inventing the earliest type of trunk buddle (a tank traditionally used in mineral processing for the gravity-separation of ores) (Timberlake, 2019). In all such cases (including that of the putative launder washery on Copa Hill) this is not a matter of sophistication in technology, but rather a matter of sophistication in skills. This type understanding gained from comparative study as well as archaeological experiment helps to explain how copper was won from some of the most unlikely of sources in the mountains of West Wales. This may well be a case of 'needs must' and opportunism on behalf of local agriculturists rather the discovery and working of any sort of rich deposit. It seems this all changed with the discovery of the larger and richer bodies of ore at the Great Orme Mine around about 1600 BC (Williams, 2023). The latter event would appear to correspond with the simultaneous abandonment of the smaller Welsh-English mines worked during the earlier Bronze Age, although other causes such as exhaustion of the easily won ores and flooding caused by a deteriorating climate may also have been responsible.

Figure 28. Gold 'head' washed-out of the hematite concentrate, Sakdrisi, Georgia. Photo: courtesy of the DBM, Bochum.



Summary points

1. Across the UK the sites of some 15 identified Early Bronze Age copper mines are associated with the distribution of cobble stone mining tools. The majority of these mines and prospecting sites are to be found in Wales; particularly in West-Central Wales, where we find some of the earliest dated workings.
2. Within mainland Britain, fully-grooved hammer stones are found at only one site (at Alderley Edge). Elsewhere over 90 % of the tools used are completely un-modified; with only a small number of them notched, or more rarely partially-grooved. It appears that un-modified cobbles were also hafted, or else used as hand-held implements. Most of these tools seem to be linked to mining rather than ore crushing, yet clearly their use was utilitarian, and they would have had dual or multiple function(s).
3. In terms of classification, a series of different stone tool use-types and morphologies can be identified, although the degree of re-cycling present at most sites means that we are dealing instead with a continuum, where more than 40 % of the tools, whether near-complete or fragmentary, are being re-used.
4. The recognition and collection of debitage resulting from the use of these cobble tools should be an important part of the archaeological excavation strategy of these prehistoric mines and processing sites. The association and proximity of a complete range of debitage may be used to ascertain the in situ-ness and contemporaneity of these tools with the other

archaeology, just as the analysis of type can show whether these result from mining or from ore processing (crushing and grinding) activities. Needless to say, some stone tools may be used for both purposes.

5. Where the mining sites lie within c.25 km of the coastline, we see a preference for the use of beach pebbles, therefore the exploitation of these sites may accommodate the seasonal transport of tools, and possibly also mining campaigns. Inland of these a more opportunistic strategy of raw material procurement is seen – such as the preferential use of river pebbles. Where suitable examples are in short supply this may revert to the collection of erratic cobbles from glacial moraine or outwash gravels. Only rarely do we witness the 'quarrying' of tools from outcrop. Some examples have been noted, however, from the mines on the east side of Plynlimon.
6. Experiments have been undertaken in the making and using of prehistoric mining (cobble stone) tools which have helped inform our opinion on how these were best used, and how long they lasted prior to substitution and repair.
7. Firesetting experiments have likewise been helpful in allowing us to estimate fuel consumption, and the requirements for timber, and to help explain how some of the hardest rocks might have been worked.
8. Finally, experiments in ore processing have been particularly useful in that they have demonstrated how relatively low-grade ores, or ores with inconsistent metal values, were processed and the mineral recovered using simple technologies. This would have involved the hand-selection and picking of mineral samples alongside the actions of rudimentary (but skilled) washing and gravity separation of mineral mixtures.

Concluding comments

In all probability mining with stone tools represents a utilitarian technology which could, and almost certainly did develop spontaneously and independently across the globe at the very beginning of the first metal working period(s); the product of environmental determinism, and to some degree the diffusion of skills and practices.

Given the obvious similarities between the assemblages of cobble stone mining tools found at a 10000 year old hematite pigment mine at Taltal in Chile and a 4000 year old copper mine on Copa Hill, Cwmystwyth in Wales, what then are the differences? The former should have implements for the fine grinding of hematite, but beyond that, it should be possible to see some of the same functional types of tool appearing as a result of similar utilitarian needs associated with the mine's development, and the ensuing wear and fragmentation of the implements used.

The collection and use of these tools reflects the continuation of what was effectively a stone age technology employed in the earliest extraction of ores and the production of metal. In general terms the stable ergonomics of stone tool use pre-dates the arrival into general circulation of bronze in such abundance as to become expendable as tools; this is particularly the case where it is those individuals of modest status who are undertaking the mining (Shennan, 1999). This appears to be the situation in Europe right up until the Middle Bronze Age - Late Bronze Age expansion in metal production.

As regards the mining and ore processing techniques experimented with in this study, we can be pretty certain that most prehistoric miners used only a very basic toolkit, but used this in a way that sometimes involved quite skilled and complex processing sequences. Most impressive was the ingenuity of these people, their intuitive geological 'knowledge', and a completely different approach to timescale, economy and the effort of collective labour.

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References

Ancel, B. and Pye, V. 2008. L'abbatage par le feu: une technique minière ancestrale. *Archéopages Mines et Carrières,* 22, pp.34-41.

Anreiter, P., Brandstätter, K., Goldenberg, G., Hanke, K., Leitner, W., Nicolussi, K., Oeggl, K., Pernicka, E., Schaffer, V., Stöllner, Th., Tomedi, G. and Tropper, P. eds., 2013. *Mining in European History and its Impact on Environment and Human Societies – Proceedings for the 2nd Mining in European History Conference of the FZ HiMAT, 7.-10. November 2012, Innsbruck*. Innsbruck: innsbruck university press (IUP) (= Conference Series).

Barnatt, J. and Thomas G., 1998. Prehistoric mining at Ecton, Staffordshire: a dated antler tool and its context. *Mining History: Bulletin Peak District Mines Historical Society,* 13(5), 72-78.

Bick, D., 1976. *The Old Metal Mines of Mid-Wales,* Part 3. Cardiganshire north of Goginan. The Pound House. Newent, Glos., UK.

Bick, D.E. and Davies, P.W., 1994. *Lewis Morris and the Cardiganshire Mines.* National Library of Wales, Aberystwyth.

Bird, J.B., 1979. The 'Copper Man': a prehistoric miner and his tools from Northern Chile. In: E.P. Benson, ed. 1979. *Pre-Columbian Metallurgy of South America.* Washington. pp.105-132.

Bowen, E. and Gresham C., 1967. *History of Merioneth, Volume 1.* Dolgellau: Merioneth Historical and Record Society. p.55 (quote from R. Fenton's '*Tours in Wales 1804–1813*' re-published as a Supplement in *Archaeologia Cambrensis* (1917)).

Briggs, C,S., 1976. Note on prehistoric mining in Anglesea. *Historical Metallurgy,* 10(1), p.43.

Briggs, C.S., 1988. The location and recognition of metal ores in Pre-Roman and Roman Britain and their contemporary exploitation. In: J. Ellis-Jones, ed. 1988. *Acta of British School in Athens Centenary Conference on Ancient Mining and Metallurgy.* University of Wales, Bangor. pp.106-114.

Briggs, C.S., 1993. Early Mines in Wales again: a reply to Budd et al. 1992. *Archaeology in Wales,* 34, pp.13-15.

Browne, T., 1995. The Mysteries of Alderley Edge. *The North West Geologist,* 5, pp.18-21.

Cambrian Archaeological Association, 1866. *Stone hammers from Blaendyffryn Mine.* Machynlleth: Meeting Report (Temporary Museum in Machynlleth, August 1866), Archaeologia Cambrensis. p.544.

Craddock, B., 1990. The experimental hafting of stone mining hammers. In: P. Crew and S. Crew, eds. 1990. *Early Mining in the British Isles. Plas Tan y Bwlch Occasional Publication*, 1. Maentwrog, Snowdonia. p.58.

Craddock, B., Cartwright, C., Craddock, P.T. and Wray, W.B., 2003. Hafted stone mining hammer from Chuquicamata, Chile. In: P. Craddock and J. Lang, eds. 2003. *Mining and Metal Production through the Ages.* London: British Museum/Archetype. pp.52-68.

Crew, P. and Crew, S. eds., 1990. *Early Mining in the British Isles.* Plas Tan y Bwlch Occasional Publication, 1. Maentwrog, Snowdonia.

Davies, O., 1937. Mining Sites in Wales. London: Report of Annual Meeting of the British Association for the Advancement of Science, Section H4. pp.301-303.

Davies, O., 1938. Ancient Mines in Montgomeryshire. *Montgomeryshire Collections* 45, pp.55-60 and 152-157. Powysland Field Club, Welshpool.

Davies, O., 1947. Cwm Ystwyth Mines. *Archaeologia Cambrensis,* 100, pp.61-66.

Dawkins, W.B., 1875. On the stone mining tools from Alderley Edge. *Proceedings of the Literary and Philosophical Society of Manchester,* XIV, pp.74-79.

Dutton, L. and P. Fasham, 1994. Prehistoric Copper Mining on the Great Orme, Llandudno, Gwynedd. *Proceedings of the Prehistoric Society,* 60, pp.245-286.

Ford, T.D., 2000. Geology of Ecton and other north-east Staffordshire mines. *Mining History: Bulletin of the Peak District Mines Historical Society,* 14(4), pp.1-22.

Gale, D. 1995. *Stone tools employed in prehistoric mining.* Ph. D. University of Bradford.

Hughes, S.J.S., 1981. *Ancient Mining in Mid Wales.* MA thesis University of Manchester, UK.

James, S., 2011. *The economic, social and environmental implications of faunal remains from the Bronze Age copper mines at Great Orme, North Wales*. Ph. D. University of Liverpool.

Jenkins, D.A., 1995. Mynydd Parys Copper Mines. *Archaeology in Wales,* 35, pp.35-37.

Jenkins, D.A. and Timberlake, S., 1997. *Geoarchaeological research into prehistoric mining for copper in Wales. A report to the Leverhulme Trust*. University of Bangor.

Jenkins, D.A., Timberlake, S., Davidson, A., Mal, K., Marshall, P., Mighall, T., O'Brien, C. and Smith, D.N., 2021. Copper Mining in the Bronze Age at Mynydd Parys, Anglesey, Wales. *Proceedings of the Prehistoric Society,* 87, pp.261-291. http://dx.doi.org/1017/ppr.2021.4.

Jones, O.T., 1922. Lead and Zinc. The Mining District of North Cardiganshire and West Montgomeryshire. *Memoirs of the Geological Survey: Special Reports on the Mineral Resources of Great Britain,* 20.

Lentin, A.G.L., 1800. *Briefe über die Insel Anglesea*. Leipzig: Siegfried Lebrecht Crusius.

Lewis, A., 1990. Underground exploration of the Great Orme Copper Mines. In: P. Crew and S. Crew, eds. 1990. *Early Mining in the British Isles. Plas Tan y Bwlch Occasional Publication*, no. 1. Maentwrog, Snowdonia. pp.5-10.

Lewis, A., 1996. *Prehistoric Mining at the Great Orme: Criteria for the identification of early mining.* MPhil thesis University of Bangor.

Maass, A. 2005. Quelques réflexions concernant les structures minières chalcolithique de la région de Cabrières. La Première Métallurgie en France et dans les pays limitrophes. *Mémoire de la Société Préhistorique Française*, XXXVII, pp.63-70.

Mining Journal, 1869. Penpompren Mines (June 1869).

O'Brien, W., 2004. *Ross Island: Mining, Metal and Society in Early Ireland*. Bronze Age Studies 6. University of Galway.

Pickin, J., 1990. Stone Tools and Early Metal Mining in England and Wales. In: P. Crew and S. Crew, eds. 1990. *Early Mining in the British Isles. Plas Tan y Bwlch Occasional Publication*, 1. Maentwrog, Snowdonia. pp.39-42.

Pickin, J. and Timberlake, S., 1988. Stone hammers and fire-setting: a preliminary experiment at Cwmystwyth Mine, Dyfed. *Bulletin of the Peak District Mines History Society,* 10 (3), pp.165-167.

Roeder, C. and Graves, F., 1905. Recent archaeological discoveries at Alderley Edge. *Transactions of the Lancashire and Cheshire Antiquarian Society,* 23, pp.17-29.

Royal Commission on Ancient and Historical Monuments in Wales, 1911. *An Inventory of the Ancient Monuments in Montgomeryshire*. London: HMSO, no. 923.

Shennan, S., 1999. Cost, benefit and value in the organization of early European copper production. *Antiquity,* 73(280), pp.352-363.

Smith, A.D., Green, D.I., Charnock, J.M., Pantos, E., Timberlake, S. and Prag, A.J.N.W., 2011. Natural preservation mechanisms at play in a Bronze Age wooden shovel found in the copper mines of Alderley Edge. *Journal of Archaeological Science,* 38, pp.3029-3037.

Smythe, W.W., 1848. On the Mining District of Cardiganshire and Montgomeryshire. *Memoirs of Geological Survey,* 2(2), pp.655-684.

Stöllner, Th., Gambaschidze, I. and Hauptmann A. 2008. The earliest gold mining of the Ancient World? Research on an Early Bronze Age gold mine in Georgia. In: Ü. Yalcin, H. Özbal and A.G. Paşamehmetoğlu, eds. 2008. *Ancient Mining in Turkey and the Eastern Mediterranean. International Conference AMITEM 2008. June 15.-22.2008*. Ankara. pp.271-2388.

Stöllner, Th., Craddock, B., Timberlake, S. and Gambaschidze I., 2012. Feuersetzen im frühesten Metallerzbergbau und ein Experiment im frühbronzezeitlichen Goldbergbau von Sakridisi, Geeorgien. In: K. Oeggl and V. Schaffer, eds. 2012. *Der Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten. Proceedings zum 6. Milestone-Meeting des SFB HiMAT 2011.* University of Innsbruck: innsbruck university press. pp.65-76.

Thomas, P., 2018. *Studien zu den bronzezeitlichen Bergbauhölzern im Mitterberger Gebiet.* Der Anschnitt, Beiheft, 39. Bochum: Deutsches Bergbau-Museum, Rahden/Westfalen: Verlag Marie Leidorf.

Thorburn, J., 1990. Stone Mining Tools and the Field Evidence for Early Mining in Mid-Wales. In: P. Crew and S. Crew, eds. 1990. *Early Mining in the British Isles. Plas Tan y Bwlch Occasional Publication*, 1. Maentwrog, Snowdonia. pp.43-46.

Timberlake, S., 1987. An archaeological investigation of early mineworkings on Copa Hill, Cwmystwyth. *Archaeology in Wales,* 27, pp.18-20.

Timberlake, S., 1988. Excavations at Parys Mountain and Nantyreira, *Archaeology in Wales,* 28, pp.11-17.

Timberlake, S., 1989. Parys Mountain and Nantyreira C14 dates. *Archaeology in Wales,* 29, pp.41-42.

Timberlake, S., 1990a. Excavations at Parys Mountain and Nantyreira. In: P. Crew and S. Crew, eds. 1990. *Early Mining in the British Isles. Plas Tan y Bwlch Occasional Publication*, 1. Maentwrog, Snowdonia. pp.15-21.

Timberlake, S., 1990b. Firesetting and primitive mining experiments, Copa Hill, Cwmystwyth. In: P. Crew and S. Crew, eds. 1990. *Early Mining in the British Isles. Plas Tan y Bwlch Occasional Publication*, 1. Maentwrog, Snowdonia. pp.53-55.

Timberlake, S., 1990c. Excavations and fieldwork on Copa Hill, Cwmystwyth, Dyfed, 1989. In: P. Crew and S. Crew, eds. 1990. *Early Mining in the British Isles. Plas Tan y Bwlch Occasional Publication*, 1. Maentwrog, Snowdonia. pp.22-29.

Timberlake, S., 1992. Llancynfelin Mine and Nantyrarian Mine. *Archaeology in Wales,* 32, pp.90-91.

Timberlake, S., 1995. Llancynfelin and Nantyrarian Mines. *Archaeology in Wales,* 37, pp.62-65.

Timberlake, S., 1996a. Panteidal Copper Mine, Aberdovey. *Archaeology in Wales,* 36, p.107.

Timberlake, S., 1996b. Tyn y fron Mine. *Archaeology in Wales,* 36, pp.60-63.

Timberlake, S., 1998. Survey of Early Metal Mines within the Welsh Uplands. *Archaeology in Wales,* 38, pp.79-81.

Timberlake, S., 2001. Mining and prospection for metals in Early Bronze Age Britain - making claims within the archaeological landscape. In: J. Brück, ed. 2001. *Bronze Age Landscapes: Tradition and Transformation.* Oxford: Oxbow Books. pp.179-192.

Timberlake, S., 2003. *Excavations on Copa Hill, Cwmystwyth (1986-1999). An Early Bronze Age Copper Mine within the uplands of Central Wales.* British Archaeological Reports (British Series) 348. Oxford: Archaeopress.

Timberlake, S., 2004a. Pwll Roman Mine, Tre Taliesin. *Archaeology in Wales,* 44, pp.142-143.

Timberlake, S., 2004b. Comet Lode Opencast, Copa Hill, Cwmystwyth. *Archaeology in Wales,* 44, pp.139-142.

Timberlake, S., 2005a. Stone mining tools from Alderley Edge. In: S. Timberlake and J. Prag, eds. 2005. *The Archaeology of Alderley Edge - Survey, Excavation and Experiment in an Ancient Mining Landscape. British Archaeological Reports,* 396. Oxford: Archaeopress. pp.58-78.

Timberlake, S., 2005b. Experimental Mining on Alderley Edge. Part 1: A firesetting and mining experiment at Church Quarry in 1997. In: S. Timberlake and J. Prag, eds. 2005. *The Archaeology of Alderley Edge - Survey, Excavation and Experiment in an Ancient Mining Landscape. British Archaeological Reports,* 396. Oxford: Archaeopress. pp.188-192.

Timberlake, S., 2006. Excavations of early mineworkings at Twll y Mwyn (Cwm Darren) and Erglodd, Ceredigion. *Archaeology in Wales,* 46, pp.79-86.

Timberlake, S., 2007. The use of experimental archaeology/ archaeometallurgy for the understanding and reconstruction of Early Bronze Age mining and smelting technology. In: S. La Niece, D. Hook and P. Craddock, eds. 2007. *Metals and Mines: Studies in Archaeometallurgy.* London: British Museum, Archetype. pp.27-36.

Timberlake, S., 2009a. Copper mining and metal production at the beginning of the British Bronze Age. In: P. Clark, ed. 2009. *Bronze Age Connections.* Oxford: Oxbow. pp.95-122.

Timberlake, S., 2009b. The origins of metal mining in Britain - the exploration and archaeological excavations of the

Early Mines Research Group in Central Wales. *Welsh Mines and Mining,* 1, pp.3-16.

Timberlake, S., 2014. Prehistoric copper extraction in Britain: Ecton Hill, Staffordshire. *Proceedings of the Prehistoric Society,* 80, pp.159-206.

Timberlake, S., 2018. Nantyricket Mine (Loches y Lladron), River Severn, Hafren Forest. *Archaeology in Wales,* 57-58, pp.178-181.

Timberlake, S., 2019. Some provisional results of experiments undertaken using a reconstructed sluice box: an attempt to try and reproduce the methods of washing and concentrating chalcopyrite at the Middle Bronze Age ore processing site of Troiboden, Mitterberg, Austria. In: R. Turck, Th. Stöllner and Gert Goldenberg, eds. 2019. *Alpine Copper II - Alpenkupfer II - Rame delle Alpi II - Cuivre des Alpes II. New Results and Perspectives on Prehistoric Copper Production. Der Anschnitt, Beiheft*, 42. Bochum: Deutsches Bergbau-Museum, Rahden/Westfalen: Verlag Marie Leidorf GmbH. pp.1-16.

Timberlake, S. and Craddock, B. 2005. Experimental Mining on Alderley Edge. Part 2: The manufacture of stone mining hammers - the record of a communal experiment on Alderley Edge. In: S. Timberlake and J. Prag, eds. 2005. *The Archaeology of Alderley Edge - Survey, Excavation and Experiment in an Ancient Mining Landscape. British Archaeological Reports,* 396. Oxford: Archaeopress. pp.192-197

Timberlake, S. and Craddock, B. 2013. Prehistoric metal mining in Britain: the study of cobble stone mining tools based on artefact study, ethnography and experiment. *Chungara Revista de Antropología Chilena,* 45(1), pp.33-59.

Timberlake, S. and Haylock, K., 2018. Nantyreira Mine, Plynlimon, Hafren Forest. *Archaeology in Wales,* 57-58, pp.173-178.

Timberlake, S. and James, D., 2018. A New Early Bronze Age Mine Site at Cwmystwyth, Ceredigion - Archaeological Excavations at Penparc (Comet Lode (W)) in 2017. *Archaeology in Wales,* 57-58, pp.91-100.Timberlake, S. and King, C., 2005. Archaeological excavations at Engine Vein, Alderley Edge, 1997. In: S. Timberlake and J. Prag, eds. 2005. *The Archaeology of Alderley Edge - Survey, Excavation and Experiment in an Ancient Mining Landscape. British Archaeological Reports,* 396. Oxford: Archaeopress. pp.33-57.

Timberlake, S. and Marshall, P., 2013. Understanding the chronology of British Bronze Age mines - Bayesian modelling and theories of exploitation. In: Anreiter, P., Brandstätter, K., Goldenberg, G., Hanke, K., Leitner, W., Nicolussi, K., Oeggl, K., Pernicka, E., Schaffer, V., Stöllner, Th., Tomedi, G. and Tropper, P. eds., 2013. *Mining in European History and its Impact on Environment and Human Societies - Proceedings for the 2nd Mining in European History Conference of the FZ HiMAT, 7.-10. November 2012, Innsbruck*. Innsbruck: innsbruck university press (IUP) (= Conference Series). pp.57-64.

Timberlake, S. and Marshall, P., 2013 (2014). The beginnings of metal production in Britain – A new light on the exploitation of ores and the dates of Bronze Age mines. The Origins of Metallurgy in Europe. *Historical Metallurgy,* 47(1), pp.75-92.

Timberlake, S. and Mason, J., 1997. Ogof Wyddon (Machynlleth Park Copper Mine), Machynlleth. *Archaeology in Wales*, 37, pp.62-65.

Timberlake, S. and Prag, A.J.N.W eds., 2005. *The Archaeology of Alderley Edge – Survey, Excavation and Experiment in an Ancient Mining Landscape.* British Archaeological Reports, 396, Oxford: Archaeopress.

Timberlake, S., Andrews, P., Pickin, J. and Craddock, B., 2019. Aberdovey, Panteidal Copper Mine. *Archaeology in Wales,* 59, pp.117-119.

Williams, J.G., 1866. *A short account of the British Encampments lying between the Rivers Rheidol and Llyfnant in the County of Cardigan and their connection with the mines*. Cambrian Press, Aberystwyth.

Williams, R.A., 2023. *Boom and Bust in Bronze Age Britain: the Great Orme copper mine and European trade.* Oxford: Archaeopress Archaeology.

Willies, L., 1987. Ancient zinc-lead-silver mining in Rajasthan, India – Interim Report, *Bulletin of the Peak District Mines Historical Society,* 10(2), pp.81-123.

Willies, L., 1990. Kestel Tin Mine, Turkey: Interim Report, *Bulletin of the Peak District Mines Historical Society,* 12(5), pp.51-71.

Yener, K.A., Adriaens, A., Earl, B. and Özbal, H., 2003. Analyses of Metalliferous Residues, Crucible Fragments, Experimental Smelts and Ores from Kestel Tin Mine and the Tin Processing Site of Göltepe, Turkey. In: P. Craddock and J. Lang, eds. 2003. *Mining and Metal Production Through The Ages.* The British Museum Press. pp.181-197.

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