Bronze Age lead mining at Copa Hill, Cwmystwyth – fact or fantasy?

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ABSTRACT: *In a recent paper, Bick (1999) questions whether the Bronze Age mines discovered in mid-Wales were exploited for lead, or lead and silver, instead of copper and re-considers whether the ores were used for metal smelting. We present a short review of recent archaeological evidence and geochemical data from a blanket peat located close to the Bronze Age mine at Copa Hill, Cwmystwyth in order to consider the ideas presented by Bick. Increased copper concentrations in the peat profiles coincide with the known tenancy of the Bronze Age mine suggesting that the miner's primary interest was to obtain copper. Archaeological evidence suggests that copper was extracted in the form of chalcopyrite from the copper-lead-zinc sulphide veins. Only low concentrations of lead and silver are recorded in the peat and this evidence raises doubts over the mining of lead and silver at Copa Hill in antiquity.*

Introduction

The existence of Bronze Age mines in the British Isles is now beyond doubt. Archaeological excavation has identified a number of mines, dated to the early to mid Bronze Age by radiocarbon assay, in Wales (Dutton and Fasham 1994; Timberlake 1987, 1988, 1990a, 1990b, 1992a, 1992b, 1994, 1995, 1996, 1998; Timberlake and Mason 1997) (see Figure 1 for those in mid Wales) and south-west Ireland (O'Brien 1994, 1995). Two mines in England, at Alderley Edge and Ecton, have been excavated and dated to between 1900 and 1600 BC (Prag *et al* 1991, Barnatt and Thomas 1998, Timberlake in press). Other mines have also been identified using artefacts, such as stone hammers (*eg* Pickin 1988), but lack radiocarbon dates to confirm their age (Bick 1999).

Whilst the antiquity of the radiocarbon-dated mines is not in doubt, the assumption that they were primarily worked for copper ore for smelting has recently been challenged by Bick (1999). Here he questions the orthodox view that copper was the main objective for these early miners. Instead he argues that these mines were possibly exploited for lead, or lead and silver, and that these metal ores were used for other purposes such as abrasives, pigments, cosmetics or decoration. Bick argues that 'the five Bronze Age mines thus far proven have always been lead or zinc mines, with no tradition of copper mining' and, quoting Timberlake (1995), 'copper ore is present only as a very minor constituent of the lead-zinc-silver veins of the area' (Bick 1999, 7). Moreover, Bick suggests that the low grade of the copper-pyrite ores and the absence of smelting hearths or slags are possible evidence 'that the ores were never smelted'. He (*ibid*, 8) suggests that 'it is time to think the unthinkable - mining for lead or lead-silver in mid-Wales in the early to middle Bronze Age.' Taking all these points into consideration Bick provides a critical, constructive review of our understanding of these ancient mines and provides a useful starting point for planning future research.

This paper presents a review of some of the recent archaeological evidence from the excavation of the Bronze Age mine at Copa Hill conducted by the Early Mines Research Group (EMRG) and geochemical data from the blanket peat located close to the mine. Profiles of lead (Pb), silver (Ag) and copper (Cu), combined with some discussion of the archaeological evidence, are presented to examine Bick's (*ibid*) contention that lead and silver was mined in preference to copper by Bronze Age miners at Copa Hill.

Site details

On the eastern end of the Comet Lode, which strikes the top of Copa Hill on the northern slopes of the Ystwyth valley, a zone of copper mineralization exists and provides the location for the Bronze Age mine of Copa Hill (Timberlake and Switsur 1988) (Fig 2). Excavations here have shown that a prehistoric open-cast or trench mine, at approximately 420 m OD

(NGR: SN811751), was worked during the early Bronze Age (Timberlake 1990a, 1990b, 1994) (Fig 3). Archaeological excavations carried out since 1986 have included a programme of radiocarbon dating. Charcoal, antler and wood, recovered from mine sediments and spoil, produced radiocarbon dates of the early to mid Bronze Age (Timberlake 1987, 1990a, 1990b; 1995, 1998).

Methods

Field Sampling

Three monoliths were extracted (using monolith boxes of 150mm x 150mm cross section) from a cleanly exposed section of blanket peat located on an upland plateau on the northern side of the Ystwyth valley. The monoliths, labelled CH1, CH2 and CH4, were collected for geochemical analyses (Fig 4).

Laboratory methods

Three methods were employed to reconstruct metal concentrations. These were inductively coupled plasma mass spectrometry (ICP-MS) using a partial acid digestion of the peat, atomic absorption spectrophotometry (AAS) using a Kjeldahltherm total acid digestion method to produce the aliquot, and absorption spectrophotometry using a microwave digestion method to produce the aliquot.

Monolith CH1 was analysed on the Aberystwyth ICP-MS instrument. It was 180cm long and the material extracted consisted of well humified *Sphagnum* peat until 170cm depth where clay was reached. Peat for analysis was extracted by contiguous scrapes of freshly

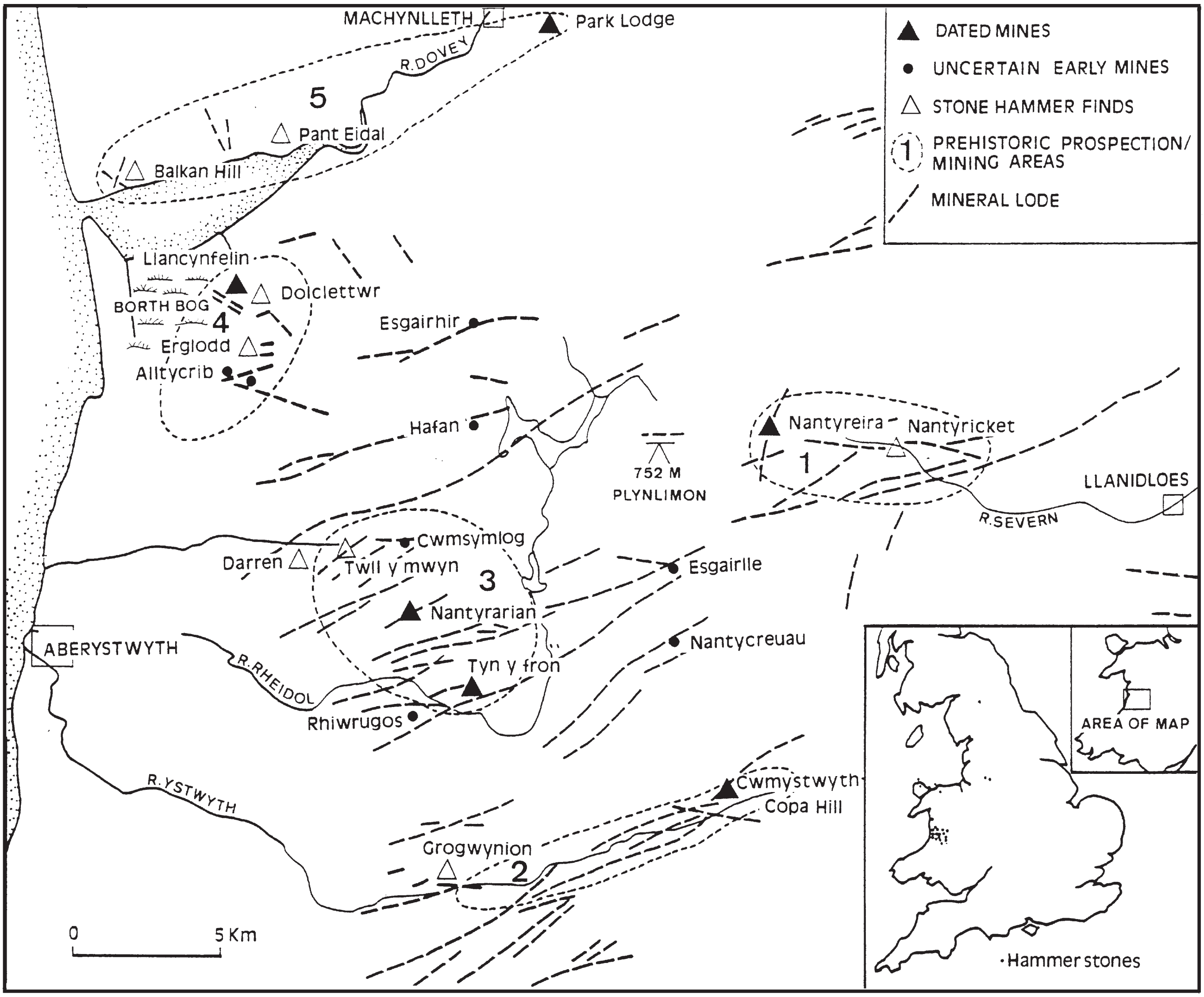


Figure 1: The location of early mines and mineral veins in mid-Wales.

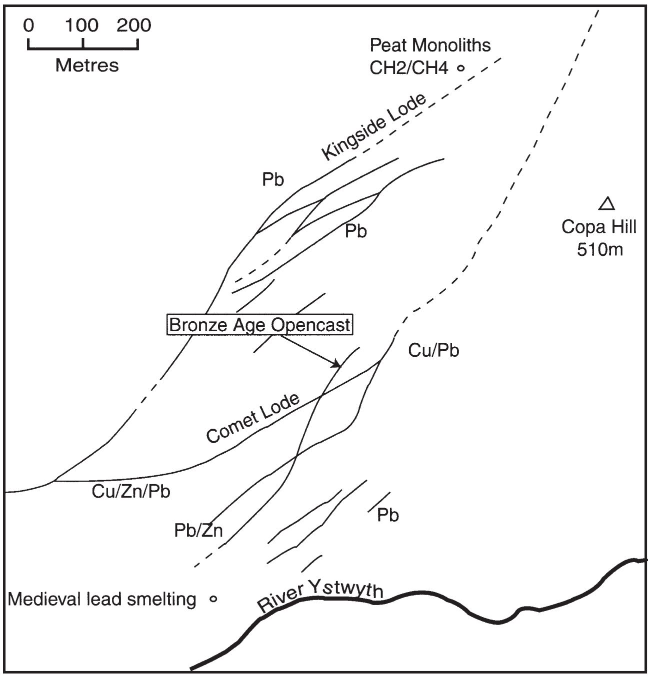


Figure 2: The position of the mineral lodes on Copa Hill in relation to the prehistoric opencast mine and the sampling site for geochemistry, labelled CH2/CH4.

exposed 50mm sections of the monolith. Each data point on the relevant figures is therefore assumed to represent an average for each 50mm section of the monolith. The solution for analysis was prepared using a partial acid digest technique. 10g samples of wet peat were oven dried overnight at 105ºC. The resulting oven dried mass was then disaggregated and treated with 25ml of 10% v/v nitric acid to digest the organic material. The samples were then placed on a hot plate and heated gradually to 100ºC and left to digest for approximately 40 hours. Each sample was then filtered using Whatman no1 paper into a volumetric flask, made up to 100ml with milliQ water and analysed by ICP-MS. Essentially this involves the feeding of the elements, in the sample solution, into a stream of argon where the elements are ionized and consequently they may be characterized according to their mass to charge ratio; ions are fed into a mass spectrometer and measured. A detailed account of the use of the ICP-MS may be found in the literature (*eg* Fuge *et al* 1992, Perkins *et al* 1993).

Samples of 10mm thickness were cut from monoliths CH2 and CH4. Contiguous samples were analysed in the basal 20cm for both monoliths. Samples were taken every 50mm between 90 and 120cm at CH4. These samples were prepared by acid digestion (HNO_3, $HCLO_4$ and H_2SO_4) for chemical analysis by AAS following the procedure outlined in detail by Foster *et al* (1987). Elements were measured using a Varian model 1472 atomic absorption spectrophotometer.

Lead concentrations were also analysed at site CH4 monolith 2b using a microwave digestion method. One gramme of each sample was mixed with 3ml of nitric acid and 1ml of hydrogen peroxide and then heated in a microwave on a set programme. Once the microwave digest was complete the samples were placed in a water cooler for 10 minutes, decanted into flasks and made

Figure 3: The prehistoric opencast on an exposure of Comet Lode, Copa Hill prior to the EMRG excavation.

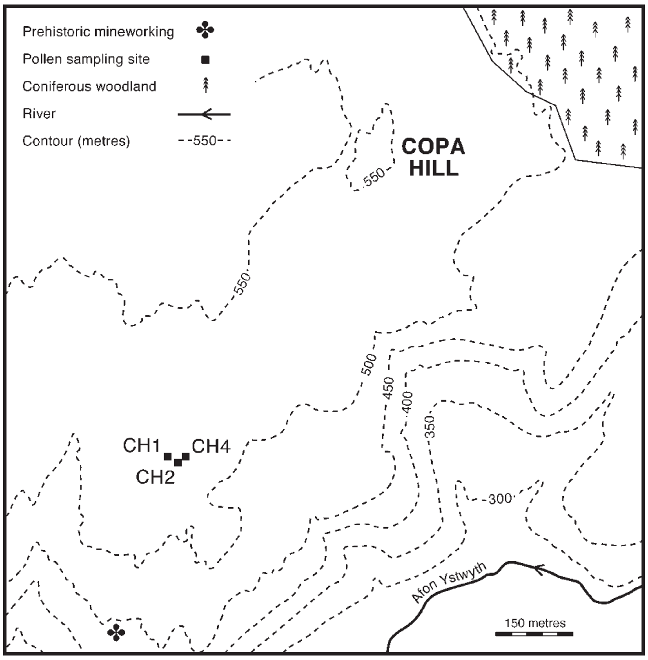


Figure 4: Location of the Bronze Age mine at Copa Hill and the sampling points for pollen and geochemistry.

up to 100ml with deionized water. Lead concentrations were then determined by AAS.

Results

Radiocarbon dating

A basal sample extracted from the CH2 peat profile (monolith 1), between 134 and 133cm depth, produced a date of 3470 ± 35 years BP. A second radiocarbon date of 2395 ± 35 years BP was derived from a sample between 105 and 106cm depth. Dates are expressed in uncalibrated years BP.

Sediment chemistry

The chemical profiles for copper (Cu), lead (Pb) and silver (Ag) are shown in Figures 5a-f. Copper shows a distinct peak between 134 and 125cm (Fig 5a). Profiles for lead are shown in Figures 5b-e. Lead concentrations peak between 125 and 137cm in Figures 5b-d, but gradually increase from 160cm down-profile in Figure 5e. The highest lead concentrations are recorded at site CH4 (Figs 5c-d). Silver is only recorded at 90 to 95 cm depth as concentrations in other samples are below the lower limit of detection (Fig 5f).

Discussion

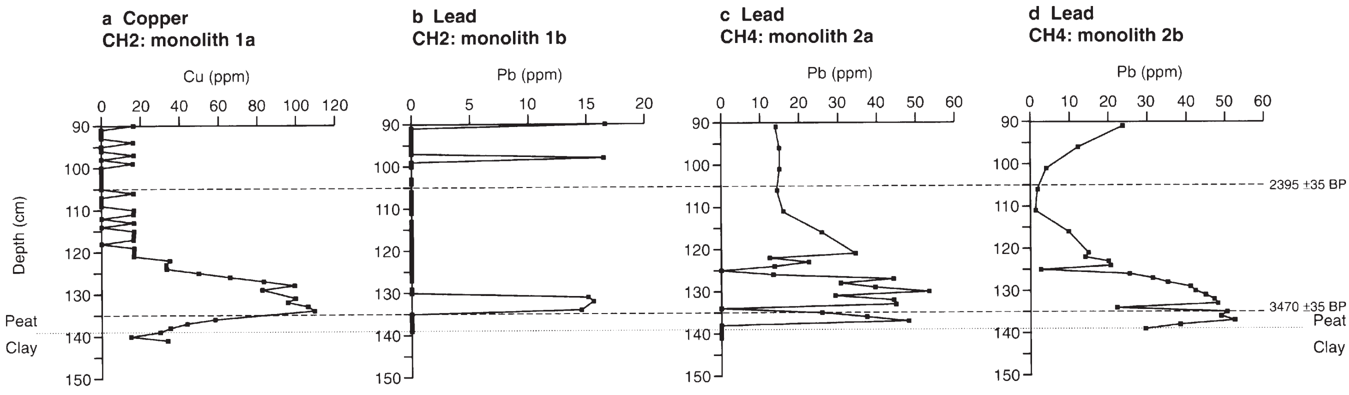
Correlating the geochemical records and the mining

The archaeological and radiocarbon evidence confirms that the Copa Hill mine was worked during the Bronze Age. Considering the radiocarbon dates obtained from the mineworking debris, it is reasonable to assume that mining was taking place for one or more periods between 3690 ± 50 and 3210 ± 80 years BP. Although the exact timespan of mining cannot be determined, the acme of activity appears to have been between 3500 ± 50 and 3405 ± 70 years BP. This is suggested by the dating of *in situ* mine deposits buried beneath several metres of infill inside the opencast. In calendar years, the most likely range of dates is 1900 to 1600 Cal BC (Timberlake 1990a, 1990b, 1995). The basal radiocarbon date of the CH2 peat profile (monolith 1), from 134 to 133cm depth, places the time of peat initiation at 3470 ± 35 years BP. A second radiocarbon date of 2395 ± 35 years BP was derived from a sample between 105 and 106 cm. Assuming that the peat accumulation rate between these two radiocarbon-dated horizons is relatively constant, the known period of Bronze Age mining corresponds in age with the vegetational record between 134 and 126cm; a revised estimate to that previously quoted by Mighall and Chambers (1993).

No radiocarbon dates have been obtained for the CH4 and CH1 monoliths. As the CH4 monolith is adjacent to CH2 and of the same depth, it is assumed there is no significant difference in the age of the peat. The peat at site CH1 is much deeper and therefore it is more difficult to correlate with monoliths at sites CH2 and CH4. However, it is assumed that any atmospheric pollution from prehistoric metal mining will occur in the basal section of the peat.

Copper

The copper peak in the basal part of the peat at site CH2 (Fig 5a) corresponds with a period of Bronze Age mining at Copa Hill. Notwithstanding the problems of making direct comparisons between concentrations of chemical elements in soils and peat it is interesting to note that Cu values peak at over 100ppm, exceeding the average natural background concentration for Cu in soils, as suggested by Macklin (1992), of 25.8ppm. Estimates of natural background concentrations do vary but do not appear to exceed the concentrations detected at Copa Hill. Baker and Chesnin (1975) suggest that lithospheric copper ranges between 2-100ppm (with an average of 20ppm). Lindsay (1979) and Parker (1981) suggest values up to 70ppm whilst Baker (1990) suggests that the average range for copper is 20-30ppm. We suggest that the correspondence between the Cu curve and the archaeological evidence, combined with the relatively high Cu values, supports the hypothesis that atmospheric pollution from prehistoric copper



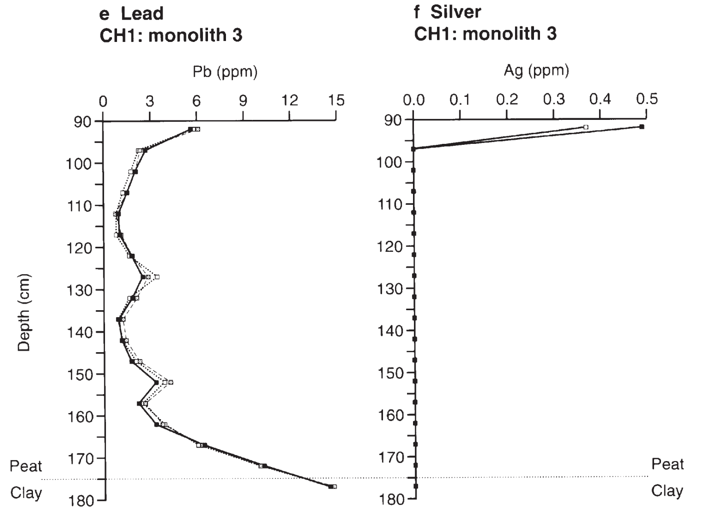


Figure 5: Chemical profiles for copper, lead and silver.
a) Copper (acid digest/AAS), site CH2
b) Lead (acid digest/AAS), site CH2
c) Lead (acid digest/AAS), site CH4
d) Lead (microwave digest/AAS), site CH4
e) Lead (acid digest/ICP-MS), site CH1 (three replicate profiles shown)
f) Silver (acid digest/ICP-MS), site CH1 (two replicate profiles shown).

mining, ore dressing and/or smelting is the most likely cause for this peak. Mighall *et al* (forthcoming) present four more copper profiles from the site using various peat acid dissolution techniques in order to eliminate method errors. An increase in copper concentration coincides with Bronze Age mining in all these profiles and they replicate the copper concentration presented in Figure 5a.

Bick (1999) suggests that the lack of convincing evidence for smelting is a reason against Bronze Age copper mining. However, a smelting site, which is thought to be associated with Bronze Age copper mining, has been discovered on the Great Orme (Chapman 1998). This suggests that copper smelting was taking place in association with mining during the Bronze Age in Wales but, at present, there is no archaeological evidence for smelting at Copa Hill. Given that the peat profile used for geochemical analysis is located at a higher altitude than the mine, any pollution must have been transported atmospherically. It remains possible that the increase in copper concentrations in the blanket peat at Copa Hill could be the result of atmospheric pollution caused by smelting. Another source might be windblown dust produced during the ore extraction process or from the surface of the prehistoric mine tips. It is believed that the copper ores were being crushed *in situ* upon these tips without the use of water for washing or concentration (see below).

Mighall *et al* (in press) consider the possibility that the relatively high copper concentrations at the base of the peat profile may be explained by processes that operate internally within the peat. Numerous studies have examined the role of pH, redox potential, the degree of peat decomposition and the position of the water table in remobilizing heavy metals (Livett *et al* 1979; Jones 1987; Livett 1988; Shotyk 1988, 1996a, 1996b; Van Geel *et al* 1989; Jones and Hao 1993; Stewart and Fergusson 1994). This research has demonstrated that the behaviour of metals in peat is complex and they may be subject to post-depositional transformation and movement. However, the results obtained by Mighall *et al* (in press) suggest that there is no statistically significant correlation between the concentrations of copper and lead with parameters such as pH, redox potential and peat decomposition at Copa Hill. This suggests that these conditions cannot explain the distribution of the metals in the peat profiles. Low concentrations of copper in the clay at the base of the peat profile suggest that the basal peat has not been contaminated with copper weathered from the bedrock.

Once deposited in peat, copper is unlikely to move as it has a strong affinity with organic matter and forms immobile organic complexes in anaerobic, acidic conditions. Peat, therefore, is an ideal environment for retaining copper (Jones 1987, Shotyk 1988). Thus, the copper concentrations in the peat at Copa Hill provide a reliable chronological record of copper extraction at the site.

Lead

An increase in lead also coincides with the period of known mining at Copa Hill for three of the four profiles shown in Figure 5. Higher concentrations of lead are recorded between 138 and 125cm at site CH4 (Figs 5c-d) whilst a short-lived peak is recorded at site CH2 (Fig 5b). Given the close similarity of the pattern of lead and copper, especially at site CH4, it is tempting also to interpret the rise in lead concentrations as the result of mining. However, such an interpretation is problematic. In all the profiles lead concentrations remain low. Lead concentration at site CH2 peaks at 132cm but never exceeds 20ppm (Fig 5b). The highest concentration of lead occurs at site CH4 when it reached 55ppm (Figs 5c-d). At site CH1, concentrations are very low and there is no clear increase in lead that might be indicative of mining. Unlike copper, lead concentrations rarely exceed the geometric mean of 30ppm for soils in England and Wales (Reaves and Berrow 1984). They also compare favourably with soil concentrations of 42ppm measured in a valley neighbouring the Ystwyth valley, which has been unaffected by mining according to Alloway and Davies (1971).

Shotyk (1988), Urban *et al* (1990) and Shotyk *et al* (1992) have suggested that lead may be prone to post-depositional transformation once incorporated into peat. Lead peaks have been attributed to the variable position of the water table and differences in peat micro-topography (especially pool and hummock formation) (Damman 1978). Stewart and Fergusson (1994) suggest that lead may be removed from permanently waterlogged, anaerobic peat but in a reducing environment of high organic content, low pH and low Eh lead (II) can be immobilized as long as there is sufficient sulphur to form sulphides in the peat. Shotyk *et al* (1997) suggest that recent evidence is clearly in favour of lead retention and a consistent relationship between the stratigraphic record of lead and the time of deposition. Therefore the record of lead in the peat at Copa Hill should be representative of the pollution history of mining in the area. The geochemical data does not support the hypothesis that lead was mined in preference to copper at Copa Hill and the evidence for mining lead in the geochemical record is equivocal.

Silver

Two profiles for silver are shown in Figure 5f. Silver concentrations only exceed the level of detection in the highest sample (90-95cm) and the data do not provide any evidence for mining pollution. However, the possibility that silver was mined at Copa Hill cannot be dismissed totally until its behaviour in blanket peat is fully understood. According to Jones *et al* (1990) most silver compounds have low solubility and are easily reduced. Silver can precipitate as sulphide minerals in highly reduced soils as it is strongly influenced by pH, redox conditions and soil organic matter content. A study of podsolic and mining contaminated soils in Wales has shown that silver accumulates in organic-rich horizons and it is unresponsive to leaching (Jones 1986, Jones *et al* 1986). Therefore, it is probable that any silver incorporated in the peat will not suffer from post-depositional transformation although Jones *et al* (1990) note that a lowering of pH can increase its mobility.

Archaeological and mineralogical evidence from the mine site

An understanding of the exact location(s) of the shallow 'stone hammer' workings and of the composition of the mineral vein at the points of exploitation is of critical importance in helping to resolve the question of which mineral (galena and/or chalcopyrite) was being extracted at Copa Hill by the Bronze Age miners. It is noteworthy that stone cobble mining hammers are only to be found at *one* location along the north side of the Ystwyth valley; at a point at the eastern end of the Comet Lode, where this vein outcrops on the brow of Copa Hill. What was so unique about this particular mineral exposure?

Chalcopyrite is a very minor component of the lead-zinc veins at Cwmystwyth. It is recorded in only 4 out of the 35 main veins and there are no official returns of copper ore since at least 1800 (Hughes 1981). However, it has long been recognized that the main deposits of copper lay under Copa Hill (Fig 2), within the eastern part of the Comet Lode, an area which is often referred to as the Belshazzar Lode (Jones 1921, Hughes 1981) or the 'Copper Lode' (Smythe 1848). Smythe's account also includes the very first mention of stone tools and discussed the evidence for ancient mining upon its outcrop. Earlier still, Lewis Morris (1751) refers to both copper and lead mining on 'Copper Hill', worked by 'lessees under a pretended lease from Mr Powell (Nanteos)', work which was almost certainly carried out on this particular lode. Approximately 3500 years earlier, before hushing had been used to fully prospect the lower slopes and to remove the thick overburden of glacial moraine which concealed the continuation of the vein further downhill, one of the few places at Cwmystwyth from which copper could (realistically) have been extracted was this summit outcrop. Northwards of this point, the Copa Hill mineral veins might have been obscured by the formation of blanket peat that commenced during the early Bronze Age (Mighall and Chambers 1993).

Establishing that the opencast was, at best, a likely spot for early copper extraction, does not however, make this a copper mine. How much copper actually was there in the lode at this point, and how rich/pure was this ore? Bick is not the first person to suggest that this ancient working was a lead mine. Oliver Davies, who carried out the first excavations at this site in the 1930s, was unable to locate any hand specimens of copper minerals upon the ancient tips, and he assumed therefore, that this lode, which he knew was copper-rich downslope, contained only lead at this point (Davies 1947). Nevertheless, less than 100m downslope of the prehistoric opencast, modern (probably 19th century) mine spoil adjacent to the opening of King's Stope, contains a fair amount of discarded chalcopyrite. From the latter working an adit, known as the 'Copper Level', has been driven to a point probably 15-20m beneath the bottom of the old workings. Parts of the walls are covered with copper salts, presumably precipitated as a result of drainage and leaching of unworked mineral above (Timberlake 1993).

If the ore-bearing parts of this lode had effectively been stripped out in antiquity at the opencast mine, then the only remaining place left to sample the original composition of this vein would be at its base - assuming that the mine was abandoned for reasons other than complete exhaustion of ore. Indeed, archaeological evidence found during the EMRG's excavations, in the form of hollowed-out wooden launders - some of the earliest examples of drainage equipment known - suggest that water problems may well have hastened the end of mining (Craddock 1994, Timberlake 1994). However, archaeological excavations have failed to reach the bottom of this infilled working, although large samples from the untried lode beneath have been obtained from the buried spoil mound surrounding an 18th-19th century prospection shaft sunk through its middle. The vein is by no means rich in ore at this point, yet irregular masses and veinlets of chalcopyrite, some up to 5 cm thick in places, are visible within this carbonate/quartz-stringer veinrock, some of it with similar or smaller amounts of blende and galena (average samples were probably <5% copper ore). The wider stockwork of branching veins, which once existed above this level, may have been richer in copper, although there is still no direct way of knowing. In fact, a cursory examination of the sides of the various worked-out veins exposed during the excavations, in particular the main branch against the (north-western) footwall, reveals only the hammered remnants of this iron carbonate vein rock, within which little trace of copper mineralisation can now be seen. However, recent rock-wall coring and analytical optical mineralogy has fairly conclusively shown that this 'vein rock' contains carbonate with chalcopyrite and pyrite as dominant sulphides. Galena occurs as a distinct and separate phase of mineralisation behind this, chiefly along the slickensided footwall(s) of the vein (Ixer *pers comm*, Jenkins and Timberlake 1997). The evidence suggests that most of this carbonate vein rock was removed *en masse* during the working period of the mine, broken up and crushed on site.

As Bick (1999) has rightly pointed out, traces of lead (galena) still remain within the opencast on Copa Hill, particularly within some of the smaller branch veins. In some places these veins do just appear to have been picked at, yet elsewhere the lead ore has been taken out completely. An example of one small vein can be seen in the floor of the entrance cutting to the mine (Fig 6). An attempt has been made to extract the galena from this; a flake tool being found wedged between its sides. Furthermore, the rock floor surrounding this was scattered with large lumps of pure galena up to 70-80mm diameter (Fig 7). It is not at all clear, however, why such rich lumps of ore had not been crushed and taken away, nor why, given that this was such an accessible location, had further ore not been extracted from the surrounding vein(s), if lead was the main mineral sought. Nevertheless, there is at least some evidence for galena extraction, either in the form of lenses of crushed galena lying amongst the sediments of the working floor (these occur in alternate lead and copper rich layers), or in the (partial) but purposeful removal of this mineral from some of the galena veins.

Figure 6: Part of the excavated interior of the Bronze Age mine. The line of the galena vein shown in Fig 7 is marked. In front is a larger worked-out vein containing iron carbonate with lead and copper.

Since modern excavations began here in 1986 large amounts of galena have regularly been found as a common constituent of the prehistoric spoil both inside and outside of the mine (Timberlake and Switsur 1988). If, as seems most likely, copper was also extracted from the veins, yet it does not appear as sizeable lumps *anywhere* within the tips (even within the lumps of carbonate), it is difficult not to come to the provisional conclusion that the lead found here was being discarded, and that the copper was being crushed and/or removed. However, Bick is absolutely right to point out if copper was being extracted then there should be some evidence for it on site. The results of geochemical, grain and mineralogical analyses carried out on bulk samples of mine spoil and mine sediments in 1996 provide a possible answer. Amongst the <7mm sieved fraction, separated from a 8.3kg sample collected from the surface of one of the tips, crushed grains of highly oxidized chalcopyrite (now largely altered to goethite on the exterior and hence unrecognisable) were found (Fig 8). These grains, which may have represented the ore *lost or rejected* in crushing, are estimated to have formed a maximum of 0.5% of the finest crushed fraction of the waste tips. A similar sized sample, collected at the same time from sediments on the floor of the buried rock-cut entrance, almost certainly an area associated with processing, contained nearer 1% of visible chalcopyrite. Almost all of the chalcopyrite detected was from these smallest grain fractions, yet evidence for finely crushed galena was rare, particularly in the samples from the tips. There is some evidence to suggest that it was on the surface of these tips that much of the ore was hand-picked, separated, then crushed in the dry upon the flat surfaces of cobble hammers, used or else reused as anvil stones. Conversely, galena appears to form a much larger percentage of the coarser fractions of spoil.

The premise that mine spoil is enriched in lead and reduced in copper might also be supported by recent geochemical analysis (carried out by ICP-MS). This provided a concentration of 4300ppm Pb against 680ppm Cu for a sample of mine spoil (all fractions) collected from outside the mine, compared with 2400 ppm Pb and 5200 ppm Cu for a sample of undifferentiated sediment collected from the mine entrance (Jenkins and Timberlake 1997). Of course there could be other factors at work here, such as leaching from the tip surface and precipitation onto the floor of the mine influencing local copper concentrations, but at least we get some idea of the ratios of copper and lead remaining within these

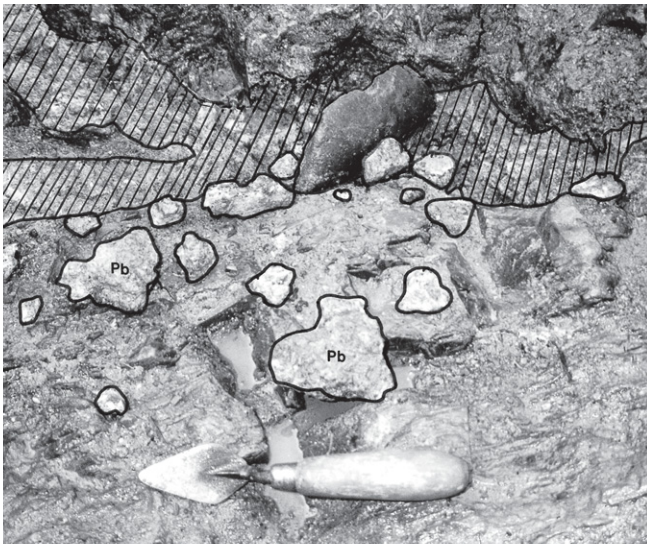


Figure 7: A part worked galena vein (shaded) within the entrance cutting of the Bronze Age mine. Note the stone tool wedged in the part-worked vein and in front the large lumps of discarded galena.

inorganic sediments.

During the final season of excavations in 1999 particular attention was paid to the recognition of chalcopyrite or oxidized chalcopyrite within mine spoil, and in particular to the micro-excavation of small areas which may once have been crushing platforms, located on either the tops or sides of these tips. One lens of finely crushed mineral within a 0.5m^2 revealed evidence for copper enrichment and the presence of hundreds of crushed grains of chalcopyrite, most <3mm in diameter and partly oxidized to goethite. Excavation of what appears to be the earliest spoil tip of the mine (the 'Lateral Tip' of Davies (1947)) has produced little evidence of galena but plenty for copper mineralisation, suggesting that the upper part of the principal carbonate vein, but not the veins which contained galena, were being exploited at this time. The evidence for the extraction of lead ore here possibly dates from the latter years of earliest phase of exploitation at the end of the Early Bronze Age, when surface reserves of copper ore were becoming exhausted and flooding was already clearly a problem (such theories await confirmation by a current programme of dating).

The Early Mines Research Group have found no evidence so far for contemporary smelting of copper or lead ores within the vicinity of this or any other of the five dated Bronze Age mines in mid-Wales. However, it may be that we are not looking for the right sort of evidence in the right sorts of places (Craddock 1994, Timberlake 1990b and 1992b). The geochemical sampling of the blanket peat above the mine reported above may yet help identify smelting sites within the area, and even on its own, this data seems to back up the archaeological evidence for copper mining.

As far as lead is concerned, there is little (but certainly some) evidence for its use within these islands prior to 1500 BC (Bick 1999), an example being the recent discovery of lead beads from a EBA-Beaker grave in Peebleshire (Hunter and Davis 1994). Yet by the end of the Middle Bronze Age and the beginning of the Late Bronze Age lead was being intentionally alloyed with copper and tin in bronze (Northover in Tylecote 1986, Rohl and Needham 1998). But what of the inception of lead metallurgy if, as Craddock (1990) predicts, smelting techniques may to some extent have developed independently of each other within the British Isles and parts of NW Europe? Even *before* it had made much of an appearance in the archaeological record, there must have been a period of considerable interest and experimentation in this metal, mostly perhaps with its

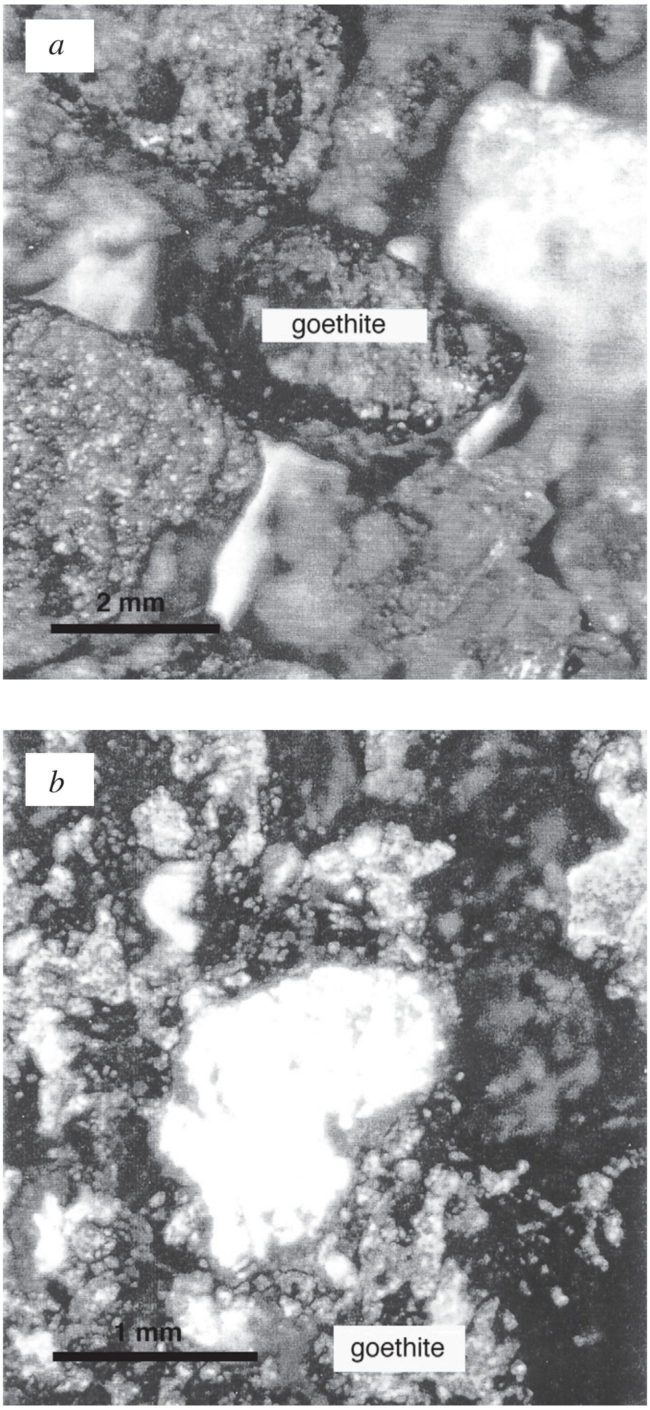


Figure 8: Crushed grains in the <7mm fraction of prehistoric mine spoil. a) goethite (x10) and b) chalcopyrite part oxidized to goethite (x25) (after Jenkins and Timberlake 1997).

principal ore, galena, a mineral which would certainly have been noticed for its 'silver-like' properties of lustre and weight, if not for its association with the precious metal, silver, itself. Yet there does not seem to be any record of silver artefacts from Britain during the Early Bronze Age. The earliest evidence for silver dates from the Middle Bronze Age, consisting of a single find of a few small beads of the metal from a grave at Gilchorn in Angus (Hutcheson 1891). Moreover, Cwmystwyth lead ore is comparatively poor in silver compared to other mid-Wales mines (Hughes 1981), therefore it is most unlikely that early metallurgical experimentation here would ever have yielded much in the way of precious metal. However, the Copa Hill galenas do require further analysis.

Conclusion

The geochemical evidence from the blanket peat located close to the Bronze Age mine at Copa Hill provides evidence of relatively high concentrations of copper coinciding with the known prehistoric tenancy of the mine. The results of the geochemical study suggest that copper mining is the most likely explanation for this peak. If mining is discounted, what process or mechanism can account for copper concentrations approximately three times greater than background values as defined by Macklin (1992)?

Notwithstanding the limited knowledge of the behaviour of lead and silver in peat, the low concentration of these metals in the basal peat at Copa Hill does not support the idea that either metal was mined for smelting. An increase in lead concentration is evident, but these concentrations rarely exceed natural background levels. If Bronze Age miners at Copa Hill deliberately extracted lead, it is puzzling that higher concentrations are not detected in the peat profiles. How do we adequately explain its absence if the miners exploited lead rather than copper? We suggest that the low lead and silver concentrations raise doubts over whether lead was smelted locally, in its own right or used in the production of other metals like bronze at Copa Hill. The recovery and experimentation with lead ores (perhaps even trial smelting) seems a plausible enough explanation for what might have been going on at Cwmystwyth and other mid-Wales mines during the latter part of this earliest mining period. Hunter and Davis in discussing the lead source for the Peebleshire beads have proposed a very similar model - lead would probably have been discovered whilst prospecting and mining for copper sulphides. Being one of the simplest ores to smelt, galena was in the process of being experimented with, small amounts being collected and smelted either deliberately or accidentally alongside copper. Alternatively, if lead was extracted for other purposes, or processed and smelted away from the Copa Hill site, it might account for the lack of a stronger signal in the geochemical records of the blanket peat.

However, Bick (1999) also raises some interesting questions concerning the discovery of stone hammers at mines which do not appear to have any copper. He presents a very good case here for further investigation, although it should also be pointed out that several of these sites (such as Erglodd and Tyn y fron) have since been shown to have copper mineralization closely associated with the dated Bronze Age workings (Timberlake 1996). A serious question mark also hangs over the reliability of the evidence regarding the identification of stone tools from a number of the other suggested sites (Esgairhir, Cwmsymlog, Nantycrieau, Rhiwrugos and Hafan (in Pickin 1988)). One must also be more careful about the evidence for copper. Whilst Morris (1744) records the discovery of silver-lead ore at the bottom of Twll y mwyn, the same lode immediately adjacent to this ancient working was rich in copper as well as in lead ore, and the mine was worked for both in the 19th century under the name of Cwm Darren (Jones 1921, Bick 1976, Foster-Smith 1979). Unfortunately, none of these sites are as undisturbed or as accessible to archaeological investigation as Copa Hill.

In our opinion the *currently available* archaeological and geochemical evidence from Copa Hill suggests that it was principally the extraction of copper ore which was the main motivation behind mining. However, the possibility of lead mining elsewhere in mid-Wales in antiquity cannot be dismissed. We need to investigate these mines of known or presumed prehistoric age to ascertain whether Bronze Age miners exploited one or a combination of copper, lead and silver. However, this paper demonstrates that we are only going to resolve some of these critical points by using an approach that combines both traditional and scientific methodologies and techniques.

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References

Alloway B J and Davies B E 1971, 'Trace element content of soils affected by base metal mining in Wales', *Geoderma* 5, 197-208.

Baker D E 1990, 'Copper', in B J Alloway (ed) *Heavy metals in soils* (London), 151-76.

Baker D E and Chesnin L 1975, 'Chemical monitoring of soils for environmental quality and animal and human health', *Advances in Agronomy* 27, 305-74.

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), 72-8.

Bick D 1976, *The Old Metal Mines of Mid-Wales Part 3: Cardiganshire - North of Goginan* (Newent).

Bick D 1999, 'Bronze Age copper mining in Wales - fact or fantasy?' *Historical Metallurgy* 33(1), 7-12.

Chapman D 1998, 'Smelting site on the Great Orme (SH78 83)', *HMS News* 38, 2-3.

Craddock P T 1990, 'Copper smelting in Bronze Age Britain: problems and possibilities', in P Crew and S Crew (eds), *Early Mining in the British Isles*, (Maentwrog: Plas Tan y Bwlch Occasional Paper 1), 69-71.

Craddock P T 1994, 'Recent progress in the study of early mining and metallurgy in the British Isles', *Historical Metallurgy* 28(2), 69-85.

Damman A W H 1978,' Distribution and movement of elements in ombrotrophic peat bogs', *Oikos* 30, 480-95.

Davies O 1947, 'Cwmystwyth Mines', *Archaeologia Cambrensis* 99, 57-63.

Dutton A and Fasham P 1994, 'Prehistoric copper mining on the Great Orme, Llandudno, Gwynedd', *Proceedings of the Prehistoric Society* 60, 245-86.

Foster I D L, Dearing J D, Charlesworth S M and Kelly I A 1987, 'Paired lake catchment studies: a framework for investigating chemical fluxes in small drainage basins', *Applied Geography* 7, 115-33.

Foster-Smith J R 1979, *The Mines of Cardiganshire*, (Sheffield: British Mining No12).

Fuge R, Palmer T J, Pearce N J G and Perkins W T 1992, 'ICP-MS techniques', *Environmental Monitoring and Testing* 2, 28-30.

Hughes S J S 1981, *The Cwmystwyth Mines* (Sheffield: British Mining Series No17).

Hunter F and Davis M 1994, 'Early Bronze Age lead - a unique necklace from southeast Scotland', *Antiquity* 68, 824-30.

Hutcheson A 1891, 'Notice of the discovery and examination of a burial cairn of the Bronze Age at the farm of Gilchorn near Arbroath', *Proceedings of the Society of Antiquaries of Scotland* 25, 447-63.

Jenkins D A and Timberlake S 1997, Geoarchaeological Research into Prehistoric Mining for Copper in Wales, A report to the Leverhulme Trust (unpubl), University of Wales, Bangor, 141pp.

Jones J M 1987, 'Chemical fractionation of Cu, Pb and Zn in ombrotrophic peat', *Environmental Pollution* 48, 131-44.

Jones J M and Hao J 1993, 'Ombrotrophic peat as a medium for historical monitoring of heavy metal pollution', *Environmental Geochemistry and Health* 15(2/3), 67-74.

Jones K C 1986, 'The distribution and partitioning of silver and other heavy metals in sediments associated with an acid mine drainage stream', *Environmental Pollution* (series B) 12, 249-63.

Jones K C, Davies B E and Peterson P J 1986, 'Silver in Welsh soils: physical and chemical distribution studies', *Geoderma* 37, 157-74.

Jones K C, Lepp N W and Obbard J P 1990, 'Other metals and metalloids', in B J Alloway (ed) *Heavy metals in soils* (London), 280-321.

Jones O T 1921, *Lead and Zinc. The Mining District of North Cardiganshire and West Montgomeryshire* (London: Special Reports on the Mineral Resources of Great Britain, Memoirs of the Geological Survey 20).

Lindsay W L 1979, *Chemical equilibria in soils* (Chichester).

Livett E A 1988, 'Geochemical monitoring of atmospheric heavy metal pollution: theory and applications', *Advances in Ecological Research* 18, 65-177.

Livett E A, Lee J A and Tallis J H 1979, 'Lead, Zinc and Copper analyses of British blanket peats', *Journal of Ecology* 67, 865-91.

Macklin M G 1992, 'Metal pollution of soils and sediments: a geographical perspective', in M D Newson (ed), *Managing the human impact on the natural environment: patterns and processes* (London), 172-95.

Mighall T M and Chambers F M 1993, 'The environmental impact of prehistoric mining at Copa Hill, Cwmystwyth, Wales', *The Holocene* 3(3), 260-4.

Mighall T M, Grattan J P, Forsyth S and Timberlake S in press, 'Tracing atmospheric metal mining pollution in blanket peat', in I D L Foster (ed), *Tracers in Geomorphology* (Chichester).

Mighall, T M Grattan J P Forsyth S and Timberlake S forthcoming, Geochemical evidence for atmospheric pollution derived from prehistoric copper mining at Copa Hill, Cwmystwyth, mid-Wales, UK.

Morris L1744, An account of the Lead and Silver mines in Cwmmwd y Perveth (National Library of Wales MSS).

Morris L 1751, 'A short history of the Crown Manor of Creuthyn in the County of Cardigan, South Wales', in S R Meyrick (ed), 1810, *A History of the County of Cardiganshire*.

O'Brien W F 1994, *Mount Gabriel: Bronze Age mining in Ireland* (Galway).

O'Brien W F 1995, 'Ross Island and the origins of Irish-British metallurgy', in J Waddell and E Shee-Twohig (eds), *Ireland in the Bronze Age* (Dublin), 38-48.

Parker A J 1982, 'Introduction: the chemistry of copper', in J F Loneragan, A D Robson and R D Graham (eds), *Copper in soils and plants* (London), 1-22.

Perkins W T, Pearce N J G and Jeffries T E 1993, 'Laser ablation inductively coupled mass spectrometry: a new technique for the determination of trace and ultra-trace elements in silicates', *Geochimica et Cosmochimica Acta* 57, 475-82.

Pickin J 1988, 'Stone tools and early mining in Wales', *Archaeology in Wales* 28, 18-19.

Prag J Garner A & Housley R1991, 'The Alderley Edge shovel: an epic in three acts', *Current Archaeology* 137, 172-5.

Reaves G A and Berrow M L 1984, 'Total lead concentrations in Scottish soils', *Geoderma* 32, 1-8.

Rohl B and Needham S 1998, *The circulation of metal in the British Bronze Age: the application of lead isotope analysis*, (London: British Museum Occasional Paper 102).

Shotyk W 1988, 'Review of the inorganic geochemistry of peats and peatland waters', *Earth Science Reviews* 25, 95-176.

Shotyk W 1996a, 'Peat bog archives of atmospheric metal deposition: geochemical evaluation of peat profiles, natural variations in metal concentrations, and metal enrichment factors', *Environmental Reviews* 4, 149-83.

Shotyk W 1996b, 'Natural and anthropogenic enrichments of As, Cu, Pb, Sb and Zn in rainwater-dominated versus groundwater-dominated peat bog profiles, Jura Mountains, Switzerland', *Water, Air and Soil Pollution* 84, 1-31.

Shotyk W, Nesbitt H W and Fyfe W S 1992, 'Natural and anthropogenic enrichments of trace metals in peat profiles', *International Journal of Coal Geology* 20, 49-84.

Shotyk W, Norton S A and Farmer J G 1997, 'Summary of the workshop on peat bog archives of atmospheric metal deposition', *Water, Air and Soil Pollution* 100, 213-9.

Smythe W W1848, 'On the Mining District of Cardiganshire and Montgomeryshire', *Memoirs Geological Survey of Great Britain* 2(2), 655-84.

Stewart C and Fergusson J E 1994, 'The use of peat in the historical monitoring of trace metals in the atmosphere', *Environmental Pollution* 86, 243-9.

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

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

Timberlake S 1990a, 'Excavations at an early mining site on Copa Hill, Cwmystwyth, Dyfed 1989 and 1990', *Archaeology in Wales* 30, 7-13.

Timberlake S 1990b, 'Excavations and fieldwork on Copa Hill, Cwmystwyth, 1989', in P Crew and S Crew (eds), *Early mining in the British* Isles. (Maentwrog: Plas Tan y Bwlch Occasional Paper No 1), 22-9.

Timberlake S 1992a, 'Llancynfelin Mine', *Archaeology in Wales* 32, 90-1.

Timberlake S 1992b, 'Prehistoric copper mining in Britain', *Cornish Archaeology* 31, 15-34.

Timberlake S 1993, 'Cwmystwyth, Wales: 3500 years of mining history - some problems of conservation and recording', *Journal of the Russell Society* 5(1), 49-53.

Timberlake S 1994, 'Archaeological and circumstantial evidence for early mining in Wales', in T D Ford and L Willies (eds), *Mining Before Powder* (Matlock Bath: Peak District Mines Historical Society 12(3) and Historical Metallurgy Society Special Publication), 133-43.

Timberlake S 1995, 'Copa Hill, Cwmystwyth', *Archaeology in Wales* 35, 40-3.

Timberlake S 1996, 'Tyn y fron Mine, Cwmrheidol', *Archaeology in Wales* 36, 61-3.

Timberlake S 1998, 'Survey of early metal mines within the Welsh Uplands', *Archaeology in Wales* 38, 79-81.

Timberlake S in press, 'Archaeological excavations at Engine Vein', in J Prag (ed), *The Archaeology of Alderley Edge* (Oxford: BAR).

Timberlake S and Mason J 1997, 'Ogof Wyddon (Machynlleth Park Copper Mine)', *Archaeology in Wales* 37, 62-5.

Timberlake S and Switsur R 1988, 'An archaeological excavation of early mineworkings on Copa Hill, Cwmystwyth: new evidence for prehistoric mining', *Proceedings of the Prehistoric Society* 54, 329-33.

Tylecote R F 1986, *The prehistory of metallurgy in the British Isles* (London).

Urban N R, Eisenreich S J, Grigal D F and Schurr K T 1990, 'Mobility and diagenesis of Pb and ^{210}Pb in peat', *Geochimica et Cosmochimica Acta* 54, 3329-46.

Van Geel B, Bregman R, Van der Molen P C, Dupont L M and Van Driel-Murray C 1989, 'Holocene raised bog deposits in the Netherlands as geochemical archives of prehistoric aerosols', *Acta Botanica Neerlandica* 38(4), 467-76.

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