Journal of Archaeological Science (2002) **29,** 1161–1188
doi:10.1006/jasc.2001.0772, available online at http://www.idealibrary.com on IDEAL®

A Palaeoenvironmental Investigation of Sediments from the Prehistoric Mine of Copa Hill, Cwmystwyth, mid-Wales

T. M. Mighall

Centre for Quaternary Science, Geography, School of Science and the Environment, Coventry University, Priory Street, Coventry CV1 5FB, U.K.

S. Timberlake

Early Mines Research Group, 98 Victoria Road, Cambridge CB4 3DU, U.K.

S. H. E. Clark

Department of Archaeology & Prehistory, University of Sheffield, Northgate House, West Street, Sheffield S1 4ET, U.K.

A. E. Caseldine

Department of Archaeology, University of Wales, Lampeter, Wales SA48 7ED, U.K.

(*Received 7 December 1999, revised manuscript accepted 12 November 2001*)

This paper investigates the use of mine sediments to reconstruct the vegetational changes and atmospheric pollution history associated with prehistoric and Mediaeval metal mining in the Ystwyth valley, Dyfed, mid-Wales. Pollen, charcoal, plant macrofossils, fossil insects and chemical analyses are presented from radiocarbon-dated sediments contained within a prehistoric mine situated on the upper slope of Copa Hill, close to the village of Cwmystwyth. The results provide additional support to the hypothesis that prehistoric mining had a negligible impact on woodland and that deforestation took place after Bronze Age mining ceased. Although high concentrations of Cu, Pb and Zn were determined from sediments of prehistoric and Roman Age, the patterns bear little resemblance to off site atmospheric pollution records and to the archaeological evidence for metal mining. Interpreting geochemical data from mine contexts is problematic as numerous factors influence the distribution and concentration of metals. However, an on-site and off-site approach to investigate human-environment interactions caused by metal mining is advocated.

Keywords: BRONZE AGE, COPPER, FOSSIL INSECTS, LEAD, MINING, PLANT MACROFOSSILS, POLLEN, WALES.

Introduction

The discovery of prehistoric mines in the British Isles has revolutionized our knowledge with regard to the origins and development of mining. Evidence for Bronze Age copper mining has now been firmly established in south-west Ireland (O'Brien, 1994*a*,*b*), and in north and mid-Wales including Great Orme's Head, Llandudno (Dutton & Fasham, 1994), Mynydd Parys (Jenkins, 1995) and Copa Hill, Cwmystwyth (Timberlake, 1990*a*,*b*). Another 20 probable prehistoric mining sites, of which five have been radiocarbon-dated, are found in Wales (Timberlake, 1994) whilst many other prehistoric mines have been excavated throughout Europe and further-afield (for example, Cernych, 1978; Craddock, 1980, 1995; Ambert *et al*., 1990; Miller, 1995). This research has largely concentrated on surveying and dating early mines, mining technology, smelting technology and provenance studies (Craddock, 1994, 1995).

The environment impact of prehistoric mining has received less attention because of the paucity of suitable deposits for palaeoecological (pollen, plant macrofossils, fossil insects, microscopic charcoal

0305–4403/02/$-see front matter

analyses) and geochemical investigation close to known mines (Mighall & Chambers, 1993*a*; Edwards, 1999). The use of trace element analysis and palaeoecological methods as a geoarchaeological tool still remains at early stage of investigation with regard to prehistoric and mediaeval mining and metalworking sites. Jenkins (1988: 104) suggested "that its development awaits the accumulation of more background data and also experimental studies on smelting, soil redistribution and other relevant systems" and this view still remains valid today.

Palaeoenvironmental data collected from prehistoric mining sites can be useful in several ways to explain human-environment interactions in the mining landscape. Pollen, plant macrofossil, fossil insects and charcoal analyses can provide supporting evidence for resource-based aspects of mining such as firesetting and the use of wood fuel and vegetational changes, especially the depletion of local woodland, whilst trace element analysis can be used to reconstruct pollution histories. Atmospheric pollution histories have been reconstructed using ombrotrophic peats in metal mining areas with a reasonable degree of success (e.g. Gilbertson *et al*., 1997; Mighall *et al*., 2000, 2002; Rosen & Dumayne-Peaty, 2001; West *et al*., 1997) but there have been few opportunities to examine ancient mine sediments. Mine spoil heaps, gallery floors and sediments that accumulate in mines and adits during and after the cessation of activities can all feasibly preserve palaeoecological remains (for example, Burnham, Burnham & Walker, 1992), and contain metalliferous waste. Without decontamination, mine waste can also leave a legacy of polluted soil, vegetation and water for several thousand years (for example, Pyatt *et al*., 2000).

This paper aims to use mine sediments to reconstruct (1) vegetational changes that occurred as a result of mining and to consider the evidence with respect to the resource-based aspects of the mine; (2) the pollution history of early metal mining in the Ystwyth valley. Samples were extracted from infill sediments within the abandoned opencast as well as from mining sediments within the mine entrance; the earliest of which are contemporaneous with early Bronze Age mining activity at Copa Hill. Pollen macrofossil, microscopic charcoal, fossil insects and chemical analyses were conducted on these samples and the results of these investigations are presented in this paper.

Site Details

The Ystwyth valley, which lies approximately 30 km ESE of Aberystwyth, Wales, has a history of metal mining spanning four millennia. Evidence for prehistoric mining occurs on the upper slope of Copa Hill. Here, an opencast mine can be found at altitude of 426 m OD, grid reference SN 8116 7520, where a Cu-Pb mineral vein known as the Comet Lode outcrops (Figure 1). Archaeological excavation of this ancient mine has provided evidence that copper mining took place here during the early Bronze Age between *c*. 2000 BC and 1700 BC and has provided much information about the techniques and problems of primitive mining. Discovered within waterlogged deposits in the mine entrance were antler picks and hammers, remains of withy handles for hammerstone tools, basketry, ropework and a section of a 5 m long drainage launder, made from a single hollowed out alder log (Craddock, 1994; Timberlake, 1996*a*). These finds represent the earliest known examples of such equipment (Timberlake, 1995). More detailed reports of the archaeological excavation can be found elsewhere (Timberlake, 1990*a*,*b*, 1993, 1995, 1996*a*,*b*, 2001, 2002*a*; Timberlake & Mighall, 1992).

There is also some equivocal evidence for phases of mining in the Ystwyth valley from the Roman period to the 1500s. Lead (Pb) enrichment in an ombrotrophic hilltop peat on the plateau of Copa Hill provides evidence for atmospheric pollution during the Roman occupation (Mighall *et al*., forthcoming) whilst a recent excavation has confirmed the presence of an early Mediaeval Pb smelting site at the base of Copa Hill (Timberlake, 2002*b*). Historical records document virtually continuous lead mining in the Ystwyth valley since the 1500s, reaching its zenith in the late 1700s by which time the mines were also being worked for zinc (Zn). Final closure of these metal mines occurred during the 1930s (Hughes, 1981; Timberlake, 1993). Detailed accounts of the historical Pb-Zn mining have been published elsewhere (Hughes, 1981, 1994; Armfield, 1989).

Stratigraphy of the mine sediments

A plan of the excavation of the mine entrance and opencast, showing the location of the stratigraphic sections from which the mine sediments were sampled is shown in Figures 2 and 3. Cross sections of the mine sediments are also shown (Figure 3a–g). Each unit has been allocated a stratigraphic unit number during the excavation of the mine by the Early Mines Research Group (EMRG). The nomenclature adopted by the EMRG is retained in this paper for consistency. Three main sections, two from an opencast area and one near to the mine entrance, were sampled for palaeoecological and geochemical analysis. The type of sediment generally pre-determined which samples were collected for analysis. In particular, sediment deposited during prehistoric mining as well as organic-rich horizons were sampled for fossil pollen, plant macrofossils and insects. The sampled sections are shown in Figures 2 and 3. A brief description of the sediments sampled is also presented in Table 1.

Excavation area D3 is located adjacent to the northwest wall of the mine (Figure 2). A small mine gallery was uncovered and described in detail by Timberlake

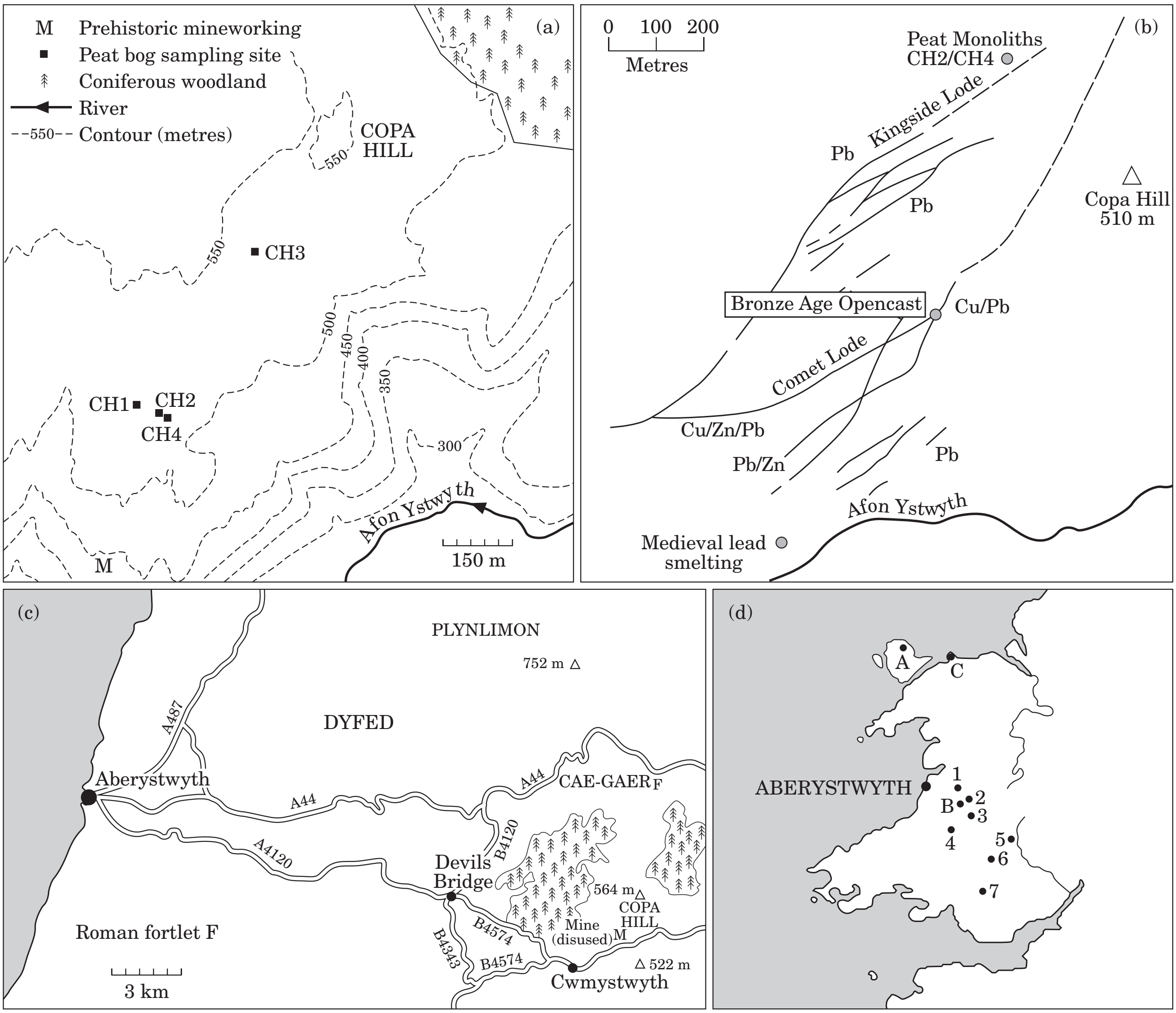

Figure 1. Location of Copa Hill, Cwmystwyth, Dyfed. (a) Location of the Bronze Age mine and the off site monoliths taken for pollen and geochemical analysis. (b) Location of the prehistoric and local mineralized veins. (c) General location. (d) Location of the prehistoric mines and other sites mentioned in the text. Prehistoric mines: A—Mynydd Parys; B—Copa Hill; C—Great Orme. Pollen sites: 1 Plynlimon; 2 Elan Valley; 3 Pwll-nant-ddu; 4 Cefn Gwernffrwd; 5 Waun Fach South; 6 Coed Taf; 7 Cefn Ffordd.

(1990*a*). Several stratigraphic units covered the bedrock in this gallery and they are shown in section C (Figure 3a). Two organic-rich sediments were sampled, 019 and 024. A sample of charcoal-rich, grey clay (stratigraphic unit 036), deposited during mining on a ledge beneath a sight bedrock overhang, was also collected from section D in excavation area D3 (Figure 3b). Close to the mine entrance, an area of approximately 5 m^2, known as area D2 was excavated (Figure 2). Section X shows the sedimentary sequence found in the south-east corner of this excavation. Of particular palaeoecological interest was unit 013, an organic-rich silt, which contained both visible plant macrofossils and insect remains and 016 (Figure 3c). The bulk of samples were collected from sections E1 and E2. These sections are located in the middle, front area of the opencast. Here a section of approximately 6 m depth of organic and inorganic sediment was excavated (Figure 3d). Samples for palaeoecological and geochemical analysis were taken from a basal shale consisting scree with some mine wastes and minor peat partings (stratigraphic unit 058), up through this sedimentary sequence which contained organic-rich clays and peat (stratigraphic units 013b, 013, 012b and 012a.a2) to a layer of laminated silt and gravel, stratigraphic unit 009. No samples were taken from stratigraphic unit 011, a grey, brown shale.

Sediments were also sampled from the entrance area. Section A shows an east-west cross section of the sediments that infill the entrance area of the mine, whilst sections F and G show the sediments (stratigraphic units 056 to 046) lying beneath and just to the

Figure 2. Plan of the Bronze Age mine showing the position of the stratigraphic sections.

side the wooden drainage launder which was used to remove water from the opencast mine (Figure 3e–g). All the stratigraphic units represented in sections F and G were sampled for geochemical analysis whilst the more organic-rich sediments were analysed for pollen, plant macrofossils and microscopic charcoal.

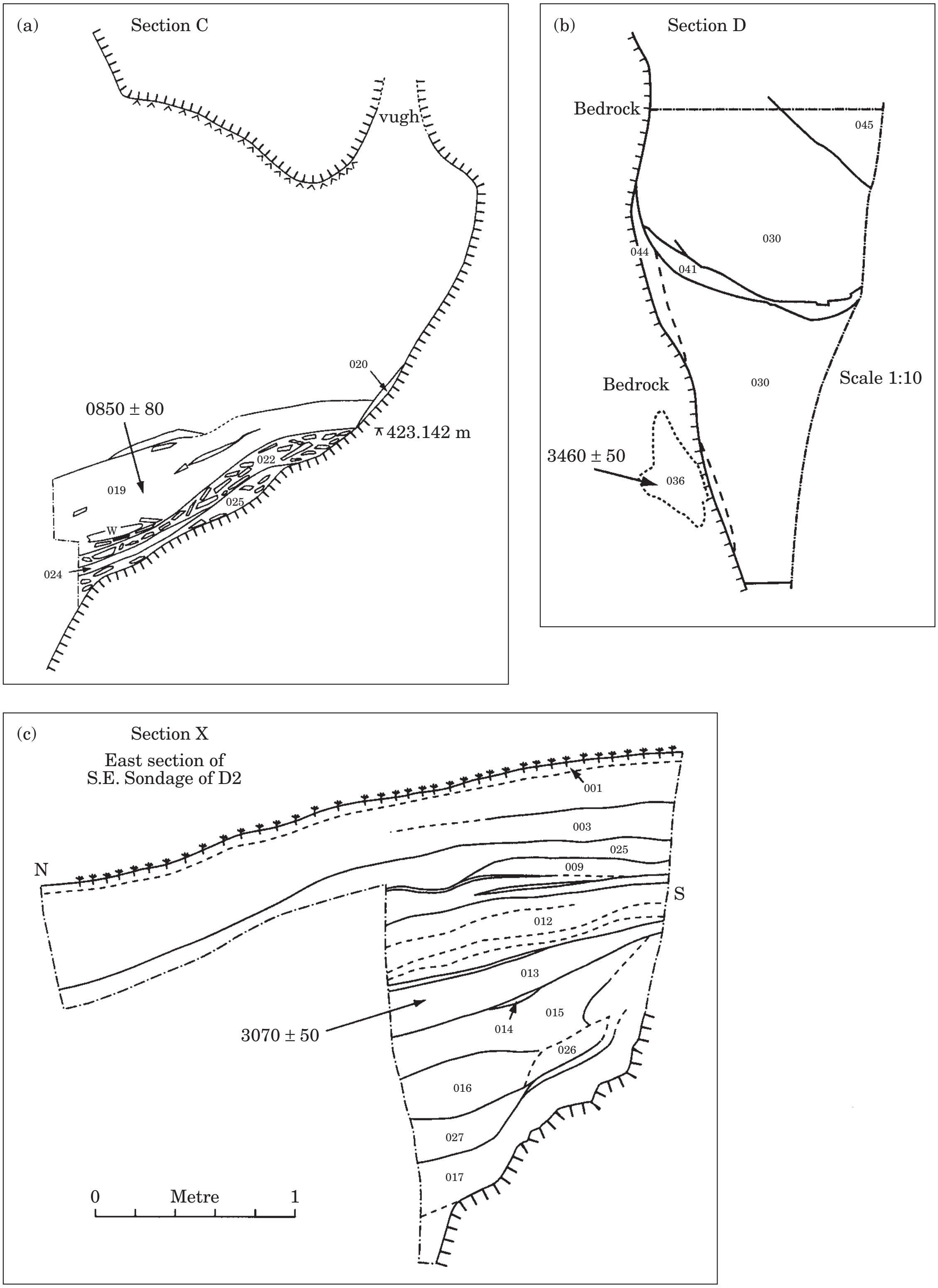

Figure 3 (a)–(c)

Figure 3. Stratigraphic sedimentary sequences from the prehistoric mine. (a) Sediments from section C. (b) Sediments from section D. (c) Sediments from section X. (d) Sediment layers for sections E1, E2 and E3 in excavated area D2. (e,f,g) Sediments from entrance area A, F and G in excavated area D7/8. Radiocarbon dates are expressed in uncalibrated years BP.

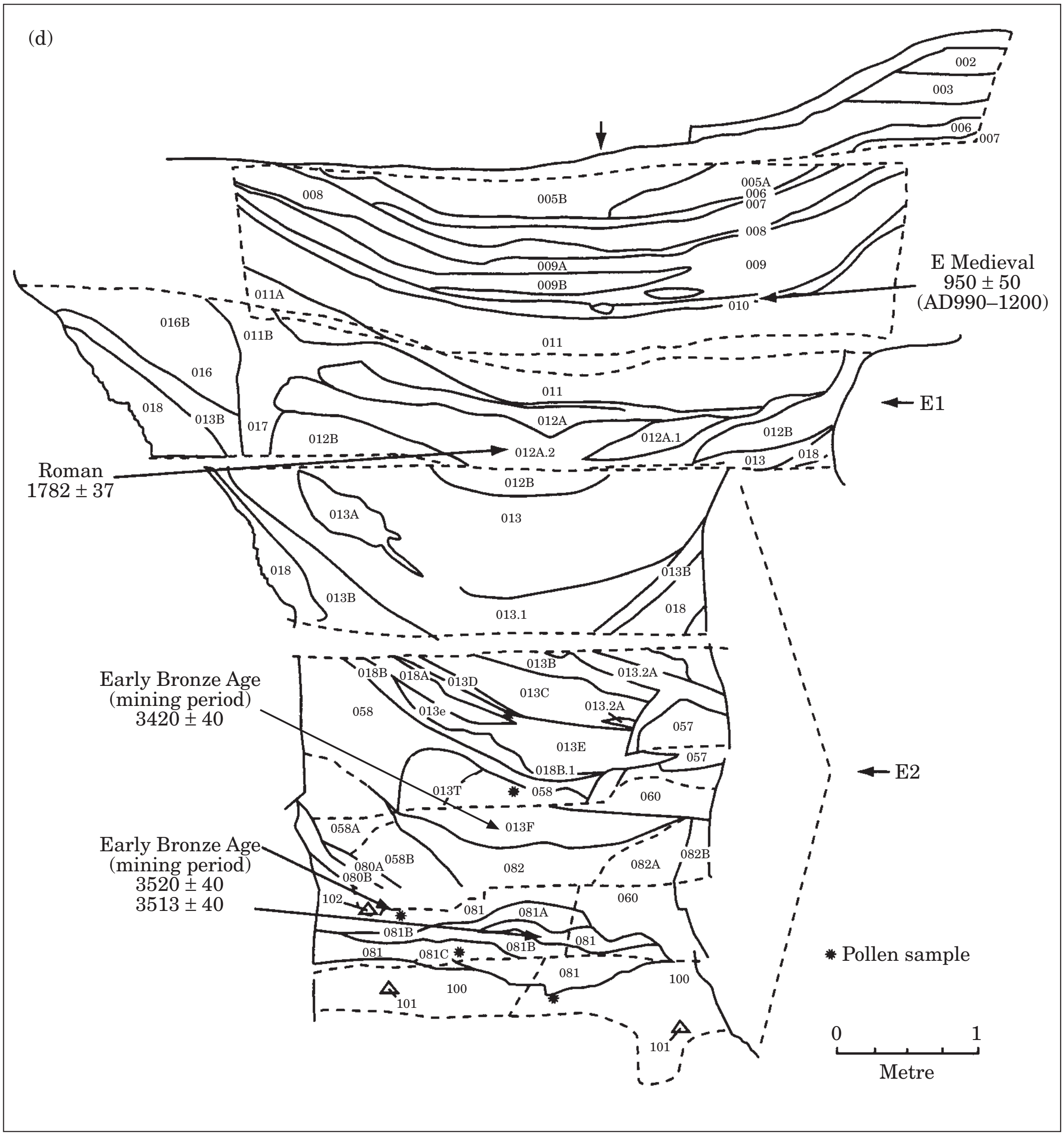

Figure 3 (d)

Methods

Pollen and charcoal

Sub-samples of 0·5–1 cm thickness and 2 g wet weight were prepared for pollen and charcoal analysis using the procedure described by Barber (1976). For inorganic sediments the density flotation procedure outlined by Nakagawa *et al*. (1998) was used to concentrate the pollen for counting. At least 500 land pollen grains were counted for each sub-sample except when pollen preservation was extremely poor or content was sparse. Pollen was identified with the aid of keys (Faegri, Kaland & Krzywinski, 1989; Moore, Webb & Collinson, 1991; Andrew, 1984), photographs (Reille, 1992) and reference to a modern type slide collection. The pollen diagrams, drawn using Tilia and Tilia.graph version 2.0.b4 (Grimm, 1991–1993), are presented as percentages of total land pollen (TLP), excluding spores and aquatics. Spore and aquatics are also expressed as a percentage of total land pollen. A cross denotes one pollen grain. Plant nomenclature follows Stace (1991) and takes into account the problems of categorizing plant species on the basis of their pollen morphology (see Bennett, Whittington & Edwards, 1994). Summary curves for trees, shrubs dwarf shrubs, (constituting arboreal pollen, AP) and

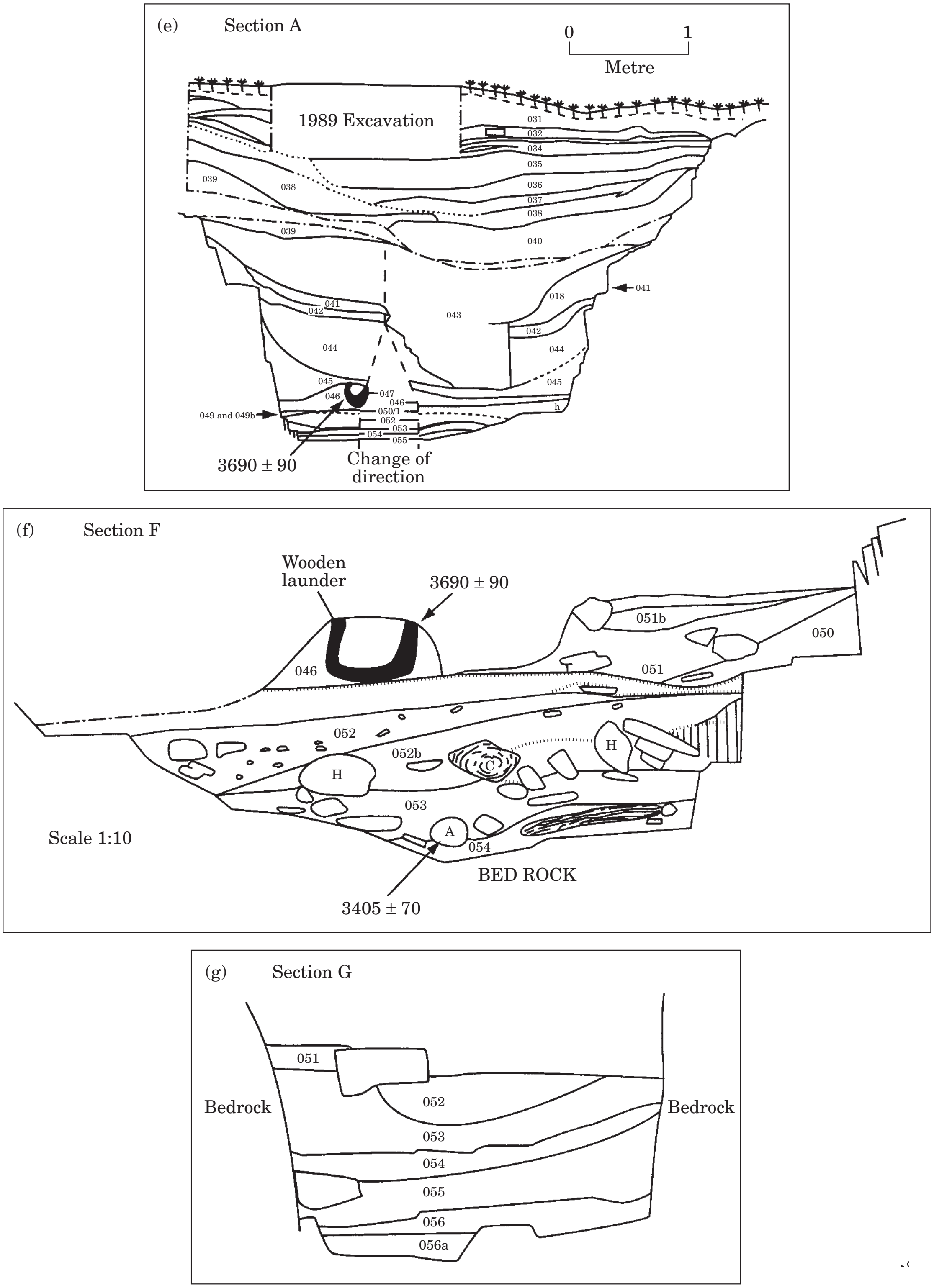
(e) Section A
0
1
Metre
1989 Excavation
031
032
034
035
036
037
038
039
038
039
040
041
018
041
042
043
044
042
044
045
045
046
047
046
050/1
052
053
054
055
049 and 049b
3690 ± 90
Change of direction
(f) Section F
Wooden launder
3690 ± 90
051b
050
046
051
052
052b
H
C
H
053
A
054
Scale 1:10
BED ROCK
3405 ± 70
(g) Section G
051
052
Bedrock
Bedrock
053
054
055
056
056a

Figure 3 (e)–(g)

Table 1. Stratigraphic description of selected stratigraphic units analysed in this study. Thickness of units in parentheses

Stratigraphic section and unit	Characteristics
Sections A, F, G	
046	Grey/black sandy layer of crushed rock, quartz shale and galena. Abundant charcoal from *in-situ* firesetting with some larger rocks and stone tool fragments (5–15 cms)
050	Layer of twigs and larger branches (e.g. birch) in orange clay. Includes a layer of decaying vegetation with some mineral fragments (galena) and hammerstone flakes (3–10 cm)
051	Similar to 050. Green–brown clay with some shale but fewer branches/twigs (3–12 cm)
051b	Similar top 051 but with an iron pan (5–8 cm)
052	Grey sandy layer with few shale fragments and little clay. Contains much crushed quartz and galena plus rotted iron carbonate (3–12 cm)
053	Light grey sand and clay with thin charcoal lens. Includes some large charcoal pieces and unburnt wood chips and twigs. Contains used withy debris (2–8 cm)
054	Gravelly layer with dark grey clay with malachite staining. Contains crushed material with charcoal and antler tool fragments (1–5 cm)
054a	Light grey sand-gravel fraction of washed, crushed waste material with shale fragments and some charcoal (<5 cm)
054b	Compressed light grey clay and shale (<5 cm)
055	Coarse shale intermixed with light grey/orange clay. Discontinuous iron pan, copper staining. Contains wood, withy fragments and some hammerstones (4–10 cm)
Section C	
024	Peat with some shale (3–5 cm)
019	Peat containing leaves, twigs, *Sphagnum* with some silt lenses and stones. Accumulated *in situ* within mine floor close to the north wall (10–60 cm)
Section D	
036	A localized layer of charcoal-rich, grey clay adhering to rock ledge (<10 cm)
Sections E1–E3	
081b	Lens of organic material including twigs, branches, grass and moss (8–20 cm)
081	Loose shale with grey clay, fragmented charcoal, branchwood, and mine timber (20–60 cm)
058	Poorly sorted shale and slate fragments in a matrix of dark brown organic clay, visible mineral matter, containing wood pieces and slate fragments (30–80 cm)
013f	Peat layer with moss and woody laminae interdigitating with lenses of shale (40–60 cm)
013b	Dark brown peat with wood pieces and a little silt (10–40 cm)
013.1/013	Undifferentiated silty organic rich layer. Plant debris and mineral matter visible. Increased silt concentration towards the base with intermittent stony layers (30–150 cm)
012b	Dark brown compressed organic sediment (peat?). Contains mineral matter including pieces of shale and stones eroded from the side of the opencast. Visible rootlets (5–15 cm)
012.a.2	Light–mid peaty grey clay and silt, with orange/red mottling. Visible sand grains. Finely banded with darker, organic rich laminae (15–40 cm)
009	Laminated gravelly silt (30–40 cm)
010	Organic silt (possible buried turf line) (10 cm)
Excavation area D2/4	
013	Organic-rich silt (10–30 cm)
016	Organic, silty clay with stone and moss fragments (20–40 cm)

herbs (non-arboreal pollen, NAP) are shown. Charcoal was estimated using the procedure outlined by Clark (1982).

Sediment chemistry

Atomic Absorption Spectrophotometry using a Kjeldahl digestion method was used to extract and determine metal concentrations from the sediments following the procedure outlined in detail by Foster *et al.* (1987). Samples of 1 cm thickness from each stratigraphic unit and oven dried at 40°C before chemical analysis by HNO_3–$HClO_4$–H_2SO_4 acid digestion. To digest the sediment in the acids, samples were placed in a Kjeldatherm digest unit for 2 h at 60°C, followed by 1 h at 110°C and then 1 h at 210°C. Each sample was then filtered through Whatman No. 1 paper and made up to a 100 ml solution after the addition of 3 ml of Lanthanum chloride. Elements of lead (Pb), zinc (Zn) and copper (Cu) were then measured using a Varian 1472 atomic absorption spectrophotometer.

Insect remains

Soil samples ranging between 0·25 and 5 l were taken from five contexts within the mine. They were processed for insect remains using the standard paraffin (kerosene) flotation method originally described by Coope & Osborne (1968). Beetles were identified using

Table 2. Radiocarbon dates from selected stratigraphic units from the Bronze Age copper mine at Copa Hill

Lab no.	Stratigraphic unit	Uncalibrated BP	Cal BC/AD (at 2σ, 95%) age ranges
Sections E1–E3			
OxA-10024	081 Burnt mine timber (102)	3520 ± 40	1950–1730
OxA-10027	081b *Sphagnum* moss	3513 ± 40	1940–1730
OxA-10043	061 Charcoal associated with extraction of galena vein	3595 ± 45	2130–1770
OxA-10022	013f Peat	3420 ± 40	1876–1841 or 1826–1818 or 1814–1797 or 1780–1676 or 1674–1621
OxA-10042	012.a2 Charcoal	1782 ± 37	Cal AD 131–344 or Cal AD 372–377
Sextion X			
BM-2733	013 Peat	3070 ± 50	1433–1210 or 1200–1192 or 1176–1167 or 1139–1132
Section C			
BM-2759	019 Leaves in peat	2850 ± 80	1287–1283 or 1261–828
Section D			
BM-2812	036 *In situ* firesetting debris (burnt and unburnt charcoal)	3460 ± 50	1891–1680 or 1670–1658 or 1651–1637
BM-2780	009 Organic buried turf	950 ± 50	Cal AD 996–AD 1214
BM-2760	027 Oak wood	830 ± 140	Cal AD 902–917 or AD 961–1406
Sections A, F, G			
Wk-9543	032 Buried turf beneath peat stack dam	387 ± 39	1430–1530 or Cal AD 1550–1640
BM-2908	047 Wooden launder. (Alder, possibly reused)	3690 ± 90	2396–2386 or 2340–2316 or 2314–1877 or 1841–1826 or 1796–1781
OxA-6684	054 Antler hammer tool lying amongst processed waste beneath the launder–within entrance cutting	3405 ± 70	1883–1521

keys and the reference collections in Doncaster Museum and the Department of Archaeology and Prehistory at the University of Sheffield. Taxonomy follows Lucht (1987). Species were assigned to one of the following ecological groups, modified from Robinson (1981) and Roper (1996), to facilitate interpretation: acidic wetland, aquatic, dung, eurytopic, euryhygric, grassland/heathland/ruderal, non-acidic wetland, wet/foul or woodland. Specimens that have not been identified to species level are unclassified unless their *Genera* only inhabits a single biotope.

Plant macrofossils

100 g subsamples from the mine were wet sieved through a stack of sieves, with a size range of 1 mm to 125 μm. Individual leaf fragments were also removed separately. Identification of seeds and fragments was made using the standard texts and by comparison with a modern reference collection. Nomenclature for the seeds follows Stace (1991). Wood samples were identified by cutting three sections i.e. transverse, transverse longitudinal and radial longitudinal and comparing them with reference slides and descriptions in Schweingruber (1990).

Radiocarbon dating

Samples taken from mine sediments were submitted to the British Museum Research Laboratory and the Oxford Accelerator Laboratory for radiocarbon dating by the Early Mining Research Group.

Results

Radiocarbon dates and chronology of the mine sediments

A chronology of the mine sediments has been established by radiocarbon age determinations of wood, charcoal, bone and organic deposits (Table 2). The radiocarbon dates are calibrated using CALIB 4.1 radiocarbon calibration programme and IntCal98 (Stuiver & Reimer, 1993; Stuiver *et al*., 1998). Radiocarbon dates of sediments from the mine are also shown in the cross sections (Figure 3) so that the chronological accumulation of sediments in the mine and the mine entrance becomes evident.

The oldest sediments occur in sections A, D, F and G. Stratigraphic sections A, F and G (Figure 3e–g) shows a sequence of sediments from 055–031 from slightly different positions within the mine entrance. The hollowed out wooden launder, in unit 046, used by the miners to drain water (Timberlake, 1995), has been radiocarbon dated to 3690 ± 90 years BP whilst a piece of antler tool lying underneath this was radiocarbon dated to 3405 ± 70 years BP, suggesting a long currency of use and re-use of the launder within the mine. The radiocarbon dates also confirm that the majority of these basal sediments within the mine entrance were deposited whilst the Cu and some Pb ores were being extracted. Indeed, it also appears that sediments 045 to 041, which include some well defined laminae of charcoal, were also deposited during mining, although a later trench cut through these appears to contain backfilled waste (043). The upper part of this sediment/spoil sequence between stratigraphic units 040 and 032 is shown in section A (Figure 3e). These horizons were deposited after the abandonment of the mine from the middle-late Bronze Age to the Late Mediaeval period. A radiocarbon date of 3460 ± 50 years BP obtained from charcoal contained within stratigraphic unit 036, the residue of an earlier mining sediment still clinging to the north face of the opencast (Figure 3b) confirms this was also deposited whilst the mine was operational.

Most of the sediments contained within sections E1 and E2 were deposited between the Bronze Age and the Early Mediaeval period (Figure 3d). A radiocarbon date of 3520 ± 40 years BP was determined for a burnt fragment of oak timber found at the base of the infill sequence (081) some 5·5 m from surface, apparently contemporaneous with a layer of moss in naturally deposited organic horizon (081b) close-by, suggesting that the base of the opencast was already flooded and partly infilled with peat, scree and waste whilst the upper parts of its were still being worked. Above this, a thick raft of woody peat (013f), the lowest part of the stratigraphic unit 013, gave a date of 3420 ± 40 years BP, still within the Early Bronze Age, but clearly at a time when work had all but ceased within the main part of the mine. Higher up the sequence, leaves preserved within the peat layer 019 perched on the floor of the mine gallery above (Figure 3a, Section C) have been radiocarbon dated to 2850 ± 80 years BP, a layer since correlated with the middle-upper part of 013 (stratigraphic unit 013.1 or 013b), an organic accumulation following the final abandonment of the mine (see also Timberlake, 1990, p. 11). Interstitial charcoal within an organic silt, radiocarbon-dated to 1782 ± 37 years BP, confirms that stratigraphic unit 012.a2 was deposited during the Roman occupation of Britain. Towards the top of the infill sequence a radiocarbon date of 950 ± 50 years BP was determined from a buried turf (stratigraphic unit 009) above the level of the mine gallery (Figure 3b; Section D), perhaps equivalent to horizon 009 or 010 in Section E1.

Table 3. Pollen data from stratigraphic unit 046

Data	Characteristics
Pollen	*Quercus* (8)*, *Corylus* (11), *Ulmus* (1), *Alnus* (1), *Poaceae* (17), *Calluna* (1), *Plantago* spp. (4), Ranunculaceae (1), Cyperaceae (2), Caryophyllaceae (1)
Spores	Polypodium (2), Pteropsida (monolete) undiff. (2), Pteridium (5)

*Denotes number of pollen grains recorded.

Pollen diagrams

Pollen data for 13 stratigraphic units are presented in Table 3 (046) and Figures 4 (054, 053, 050, 013d, 013f) 5 (058), 6 (013b), 7 (013.1), 8 (012b/013), 9 (019) and 10 (012a). Each stratigraphic unit is treated separately as it is possible that hiatuses exist between them and the nature of deposition of each unit was not always clear. 013 grades into 012b at 24 cm so both units are shown on the same diagram and a non-polleniferous shale layer occurred between 76 and 92 cm (Figure 8). Depth bars are individual to each stratigraphic unit. Overall depths of the mine sediment are shown in Table 1.

The quality of pollen grain preservation from the mine sediments at Copa Hill was analysed to establish whether the pollen record contained within a sediment reflects either the vegetation of the area at the time of deposition or reworking from eroded sediments. Four main categories were used to separate deteriorated pollen grains following Cushing (1967).

The abundance of pollen in stratigraphic unit 046, an inorganic layer that formed during or as a result of Bronze Age mining, was very poor and only 47 pollen grains were recorded (Table 3). However, the pollen recovered from this unit was in good condition suggesting that it represent primary deposition. In contrast, pollen is abundant in units 054, 053, 050, 013f, 013d, 058, 013.1, 013b, D3/019 and 012b/013 (Figures 5–9) with less than 5% of the grains showing signs of damage. This suggests that the pollen is derived from a primary source. The slight increase in degraded and corroded pollen in stratigraphic units 054, 053 (Figure 4) and at level 18 in 013b (Figure 6) possibly represent in-washed pollen although an increase in the inorganic content of the sediment is not visible in the stratigraphy of unit 013b.

The upper half of unit 012a has a higher proportion of deteriorated pollen when compared to the preceding layers but values never exceeded 10% TLP (Figure 10). Most of the damaged pollen grains are broken or crushed, with a lesser amount suffering from corrosion or degradation. Given the inorganic nature of the 012a unit, it is suggested that some of the damaged

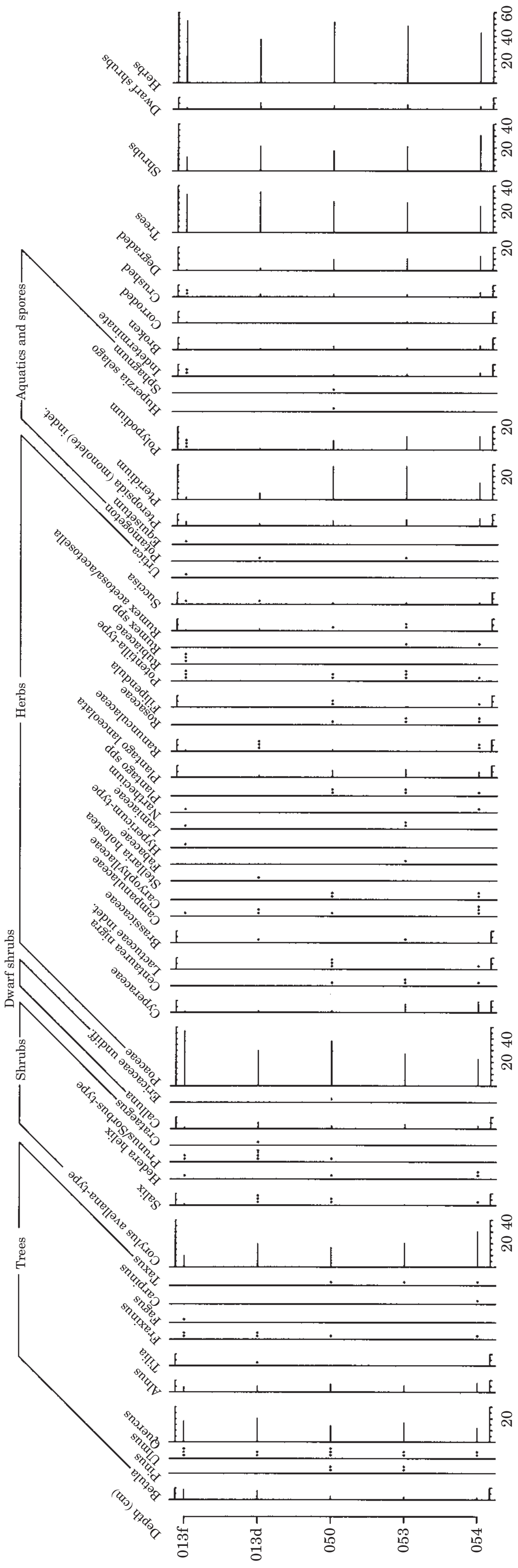

Figure 4. Percentage pollen diagram for stratigraphic units 054, 053, 050, 013d and 013f.

Copa Hill mine: stratigraphic unit 058

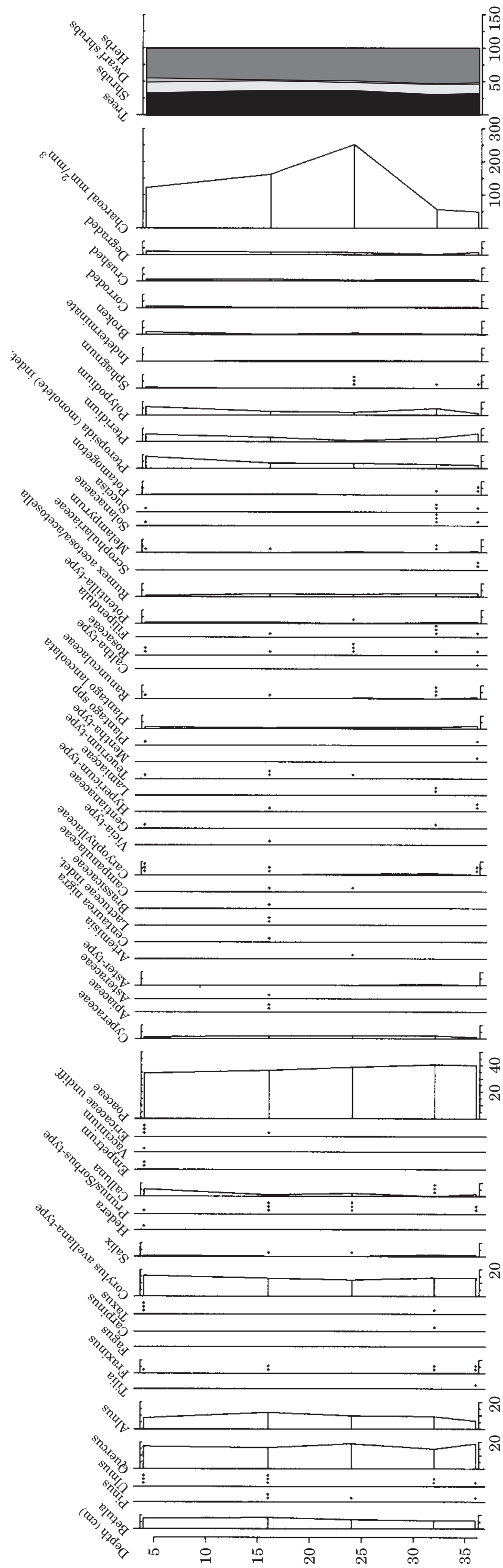

Figure 5. Percentage pollen diagram for stratigraphic unit 058.

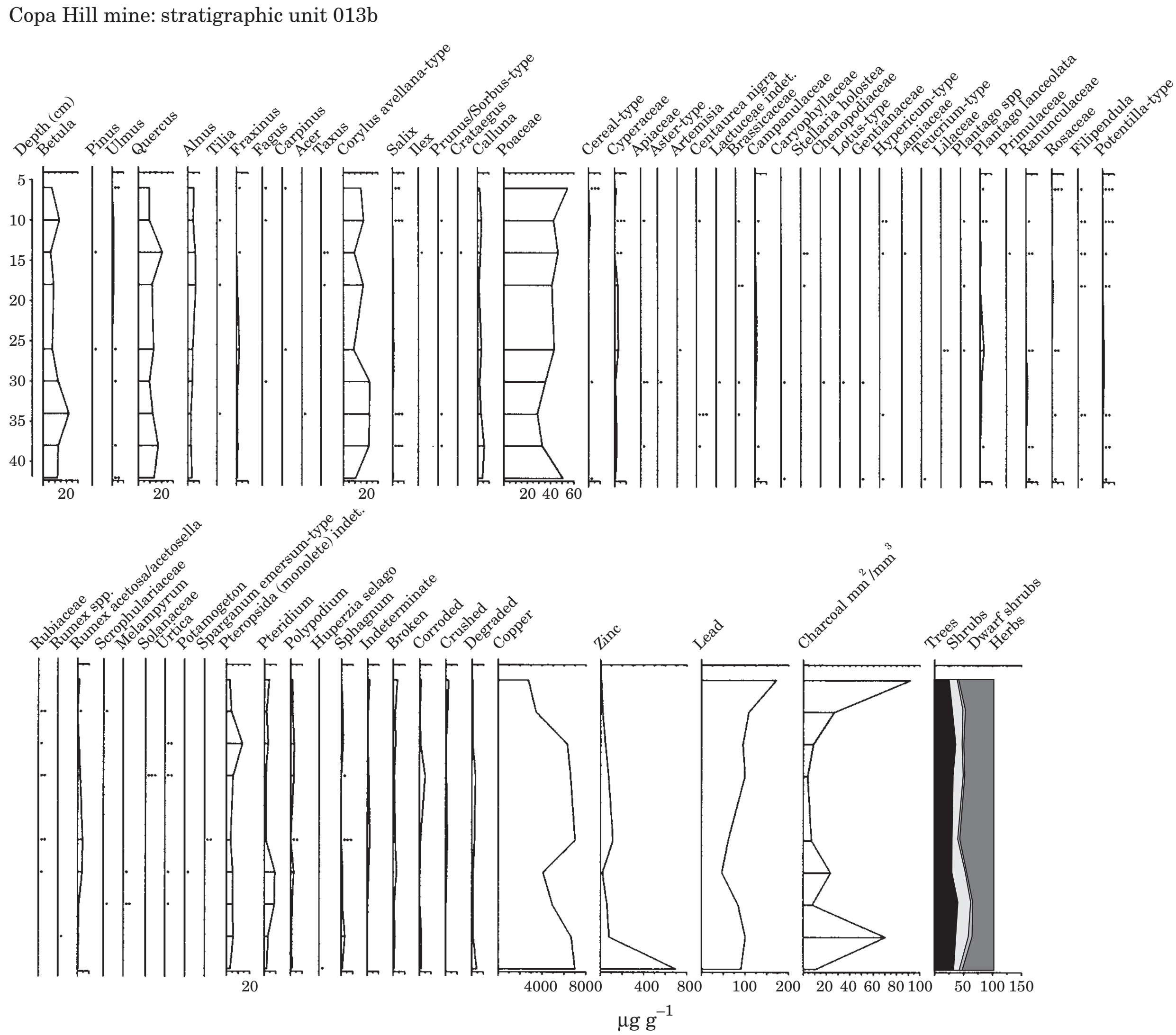

Figure 6. Percentage pollen diagram and chemical data for stratigraphic unit 013b.

and corroded pollen could be the result of physical abrasion (c.f. Cushing, 1967; Birks, 1970) as some pollen and sediments were in-washed by water into the mine. Thus, the origin of approximately 10% of the pollen contained with 012a is possibly secondary. Overall, the pollen incorporated within the organic mine sediments was in good condition with only low amounts of damaged pollen grains recorded and therefore provides a good reflection of the vegetation growing in the pollen catchment.

Plant macrofossils

The results from stratigraphic units 009, 013, 013.1, 013b, 016, 019, 024, 049b, 050, 052, 053 are shown in Table 4. The analysis reveals that whilst 013b and 013.1 contain *Betula* seeds and cone scales and possibly some leaf and/or wood fragments of *Quercus* and *Salix*, the macrofossil record is dominated by remains of *Juncus* sp. in 013b, and Poaceae, *Calluna*, *Vaccinium* in stratigraphic unit 013.1. Tree and shrub remains are more prominent in units 019, 047, 049b, 050, 052 and 053 with leaf and/or wood fragments of *Quercus*, *Corylus*, *Salix* and *Alnus*. Sediments closer to the surface, such as stratigraphic units 009, 013 and 016, are dominated by dwarf shrub and herbaceous plant and moss remains, in particular *Calluna vulgaris*, *Carex* spp., *Poaceae and Sphagnum*.

Fossil insects

Fossil insect remains recovered from stratigraphic units 019, 013.1, 013b, 012b and 009 are shown in Table 5 and divided into habitat groups in Figure 11. The fossil insect remains were well preserved in all five stratigraphic units sampled suggesting rapid incorporation into the sediment on death and continuing anaerobic conditions.

Copa Hill mine: stratigraphic unit 013.1

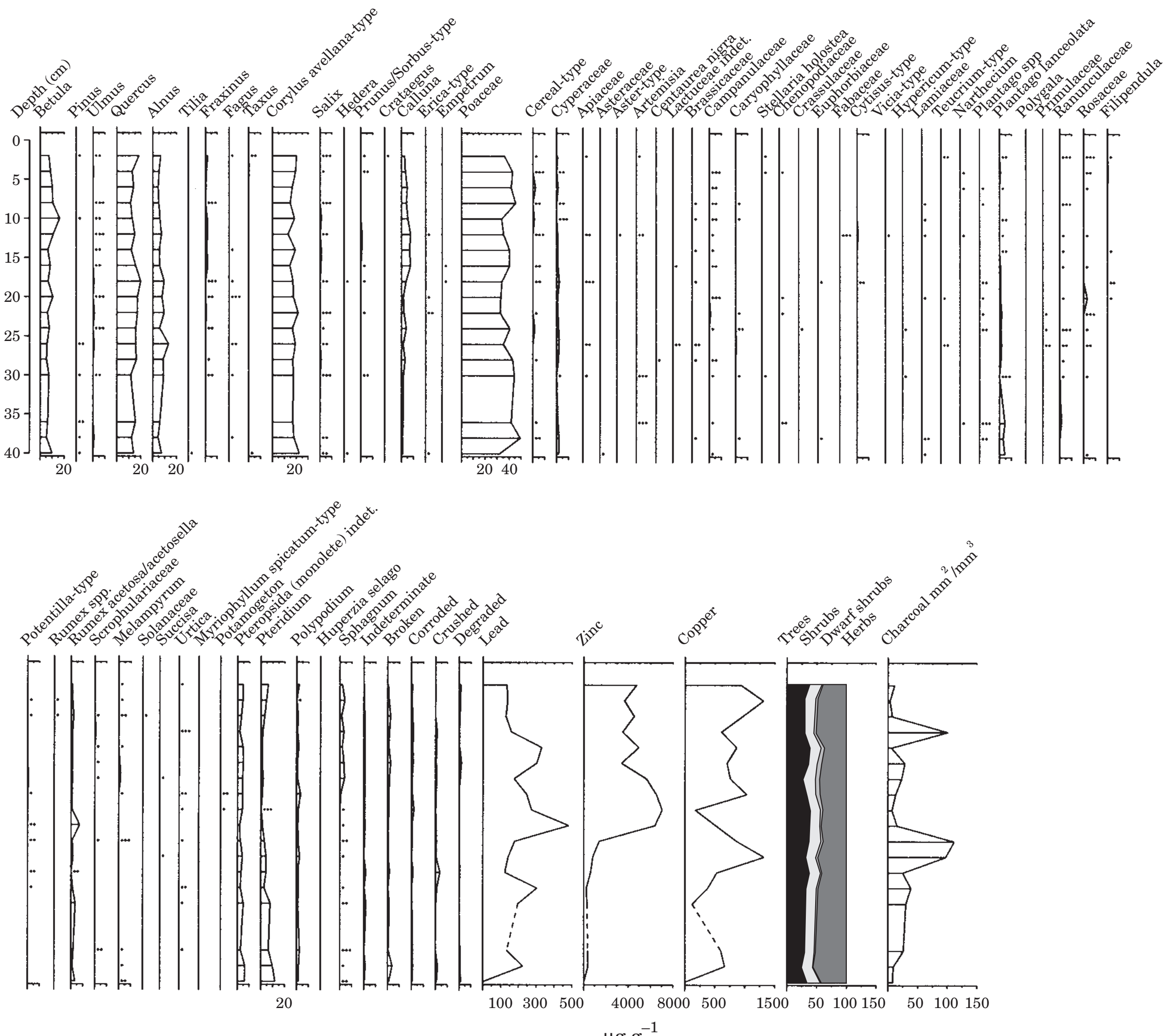

Figure 7. Percentage pollen diagram and chemical data for stratigraphic unit 013.1.

Analysis reveals evidence for *Quercus*, *Betula* and *Salix* in 013.1b and 019 and the two latter species are also in 013b. There is no positive evidence for *Juncus* spp. in any of the samples although all contain a significant percentage of species that inhabit wetlands (Figure 11). More than half of the insects from unit 012b were wetland species. Very few of the species found in any unit are acidic, wetland specialists and there are no species dependent on *Sphagnum*. All of the wetland generalists are equally at home in acidic and non-acidic wetland. Unit 013.1b had the greatest range and number of *Calluna* associates and 013b was the only one not to contain any. Species that are associated with woodland form an important component of the samples taken from stratigraphic units 013b, 013.1b and 019, but in unit 009 species associated with grassland and disturbed soil predominate. Although a number of species were found that are associated with dead wood, none are associated with structural timber, so they are unlikely to have lived within the mine. They may have been brought on to site in wood for fire setting, though no charred specimens were found. In fact the species composition suggests that most of the specimens were washed into the mine from the surrounding landscape and thus reflects local vegetation (Clark, 1997). The aquatic species could reflect on site waterlogging (Figure 11).

Sediment chemistry

The results for copper (Cu), zinc (Zn) and lead (Pb) are presented in Figures 6, 7, 8 and 10 and in Table 6.

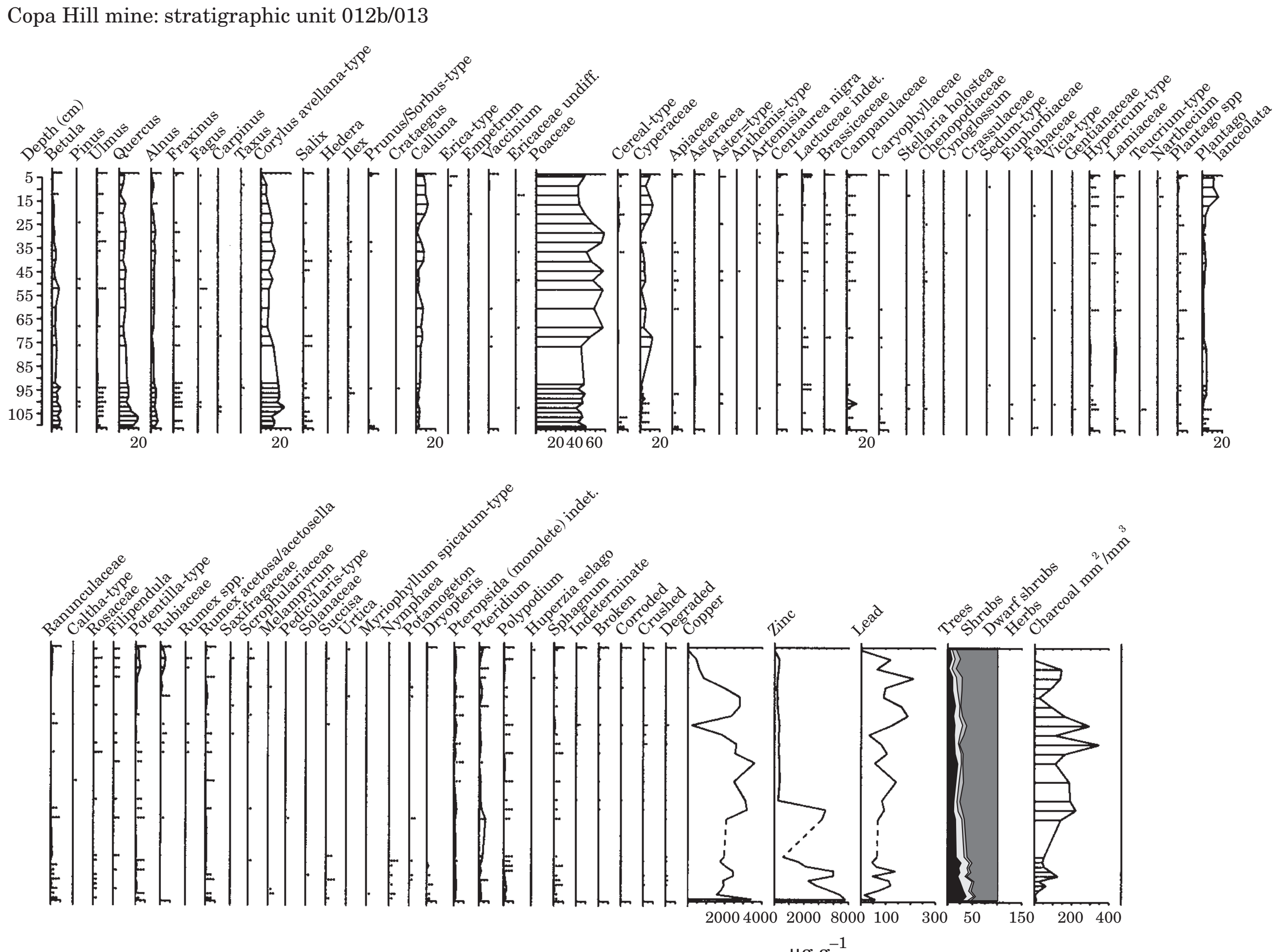

Figure 8. Percentage pollen diagram and chemical data for stratigraphic unit 012b/013.

Concentrations are highest for Cu and Zn. Cu concentrations regularly exceed 2000 μg g^{-1} in organic sediments (e.g. stratigraphic units 060, below 20 cm in 013b, 013/012b) (Table 6, Figures 6 and 8), but are lower in inorganic sediments e.g. stratigraphic units 059, 061 (Table 6) and the upper section of 012b/013 (Figure 8). Zn concentrations are more varied but are relatively low in inorganic compared to organic sediments. They exceed over 4000 μg g^{-1} in stratigraphic units 060, 053, 054b and 055 (Table 6), and peak at the base of 013b and in the upper part of 013.1 where Zn concentrations increase to over 6000 μg g^{-1} at 22 cm as the sediment becomes more organic. Zn concentrations remain above 4000 μg g^{-1} until the deposition of a shale layer between 90 and 76 cm in unit 013/012b and averages around 250 μg g^{-1} in 012a (Figures 6, 7, 8, 10). Pb concentrations remain below 400 μg g^{-1} in the sedimentary sequences found in the mine. They fluctuate between 100 and 200 μg g^{-1} in stratigraphic units 013b, 013/012b and 012a whilst concentrations occasionally exceed 300 μg g^{-1} in unit 013.1 and the stratigraphic units detailed in Table 6.

Discussion

There has been some discussion about the amount of wood utilized by prehistoric miners to extract metal ore and the impact such useage would have on local woodland. Wood demand, based on material found in ancient mines, appears to have been considerable. Estimates of wood consumption, especially for firesetting, at Bronze Age mines in Britain and Europe vary considerably, from 2000–30,000 tonnes (Cernych, 1978; Timberlake, 1990). Stos-Gale, Gale & Papastamateki (1988) suggest that metal production in the Cycladic Islands ceased during the Bronze Age owing to local deforestation. In contrast, palaeoecological data from peat bogs close to prehistoric mines and metalworking sites suggest that the impact of mining on local woodland in prehistory was negligible and any local deforestation was short-lived (Dorfler, 1995; Marshall, O'Hara & Ottaway, 1999; Mighall & Chambers, 1993*b*, 1997; Mighall *et al.*, 2000; Pott, Freund & Speier, 1992). Notwithstanding the paucity of sites investigated and the variation in their age,

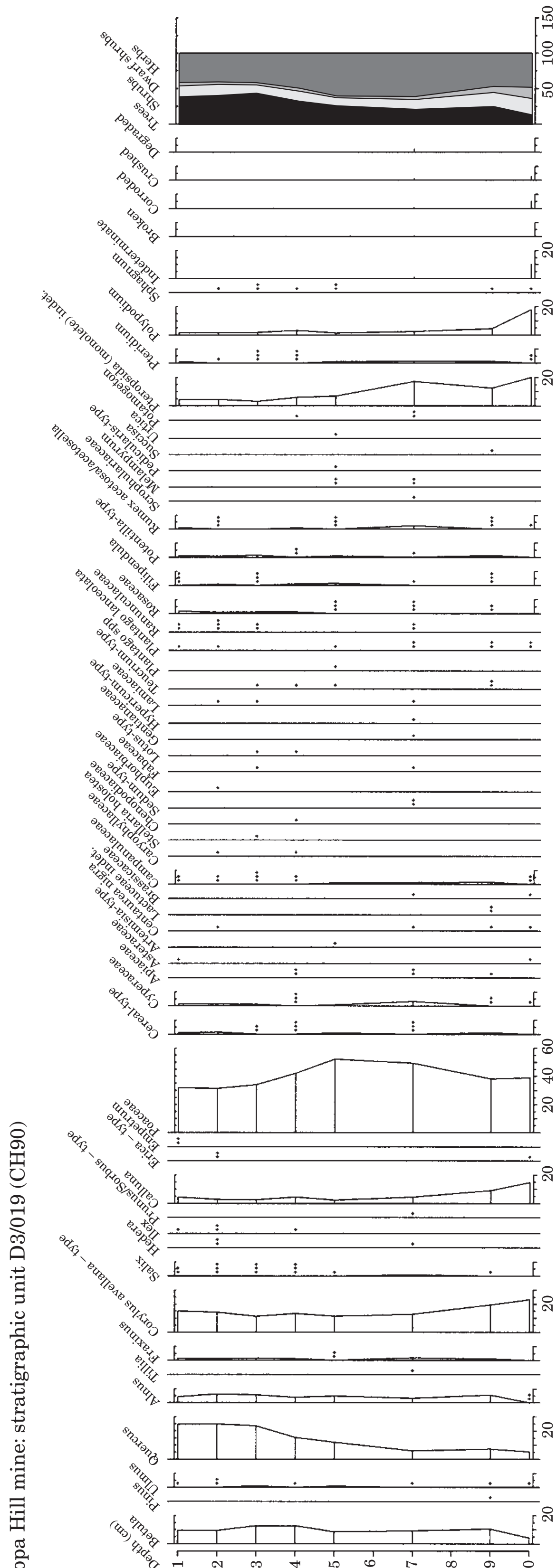

Figure 9. Percentage pollen diagram for stratigraphic unit 019.

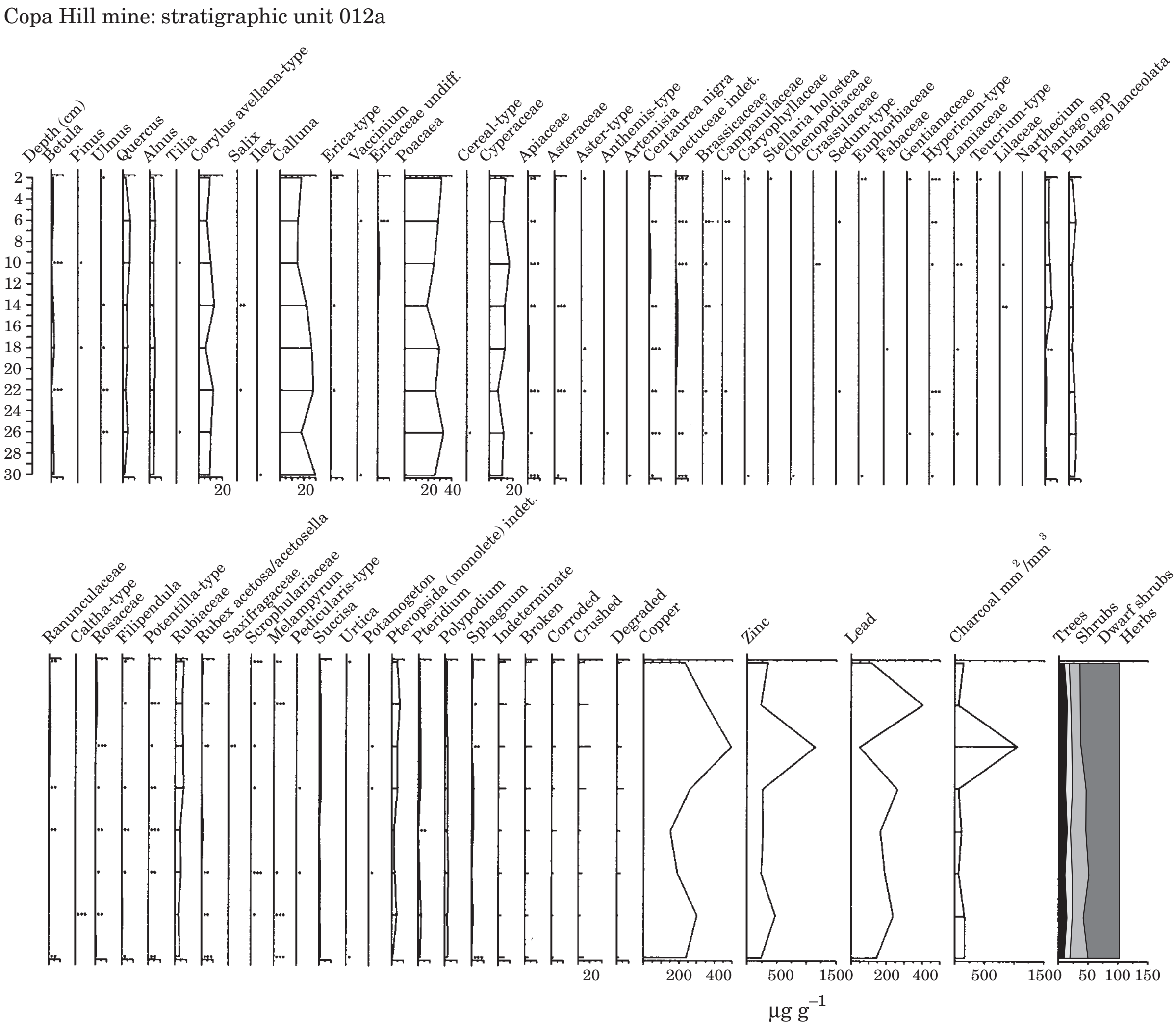

Figure 10. Percentage pollen diagram and chemical data for unit 012a.

duration and scale of mining, and the type of metal extracted or smelted, a pattern of small, short-lived local woodland clearance appears to be emerging in the palynological record. A palynological investigation of hilltop peat on the plateau of Copa Hill, approximately 500 m from the prehistoric mine, also showed little change whilst the mine was operational suggesting that the mining did not exhaust local woodland (Mighall & Chambers, 1993*a*).

Several factors, including woodland management, selectivity of wood and small scale, episodic metal ore extraction over a long time period, can determine the severity of the impact on woodland caused by mining (Mighall & Chambers, 1993*b*). However, the interpretation of the palynological data from the hilltop peat at Copa Hill is constrained by the geographical location and topographical differences of the pollen sampling site in relation to the prehistoric mine. It is conceivable that timber used by prehistoric miners was cut from woodland growing on the valley sides and floor, which are some distance from the pollen sampling location, or, alternatively, the regional arboreal signal was sufficient to buffer the pollen record against a local reduction in arboreal pollen. In either scenario, the impact of any reduction in woodland has not been recorded in pollen record captured by the hilltop peat. The Copa Hill mine sediments therefore provided an opportunity to investigate these variations in the palaeoecological data to ascertain the true extent of the impact of mining on local woodland.

The high numbers of arboreal pollen in the prehistoric mine sediments at Copa Hill provides evidence for the presence and exploitation of mixed woodland, dominated by oak and hazel. In particular, *Quercus*, *Corylus avellana*-type, *Alnus*, *Betula* and *Ulmus* pollen is found within stratigraphic units (013f, 036, 046, 050, 053, and 054) in all three excavated areas but this gives no indication to the extent or changes in woodland structure that took place. However, the total arboreal pollen percentages in those stratigraphic units which

Table 4. Plant macrofossil remains from the Bronze Age copper mine at Copa Hill. A cross denotes a presence; numbers refer to the number of fragments or seeds recovered from the samples

Sediment unit	*Betula* sp. (female cone-scales)	*Betula* sp. (leaf fragments)	*Betula* sp.	*Quercus* sp. (leaf fragments)	cf. *Quercus* sp. (leaf fragments)	*Quercus* sp. (charcoal)	*Quercus* sp. (wood)	*Alnus glutinosa* (L.) Gaertner	*Corylus avellana* (L.) (leaf fragments)	*Corylus avellana* (L.) (wood)	*Salix* sp. (leaf fragments)	*Salix* sp. (wood)	cf. *Salix* sp. (leaf fragments)	*Rubus* sp.	*Calluna vulgaris* (L.) Hull (flowers)	*Calluna vulgaris* (L.) Hull (seeds)	*Calluna vulgaris* (L.) Hull (shoots)	*Vaccinium myrtilus* L.	*Vaccinium vitis-idaea* L. (leaf fragments)	*Poaceae* >2 mm	*Poaceae* <2 mm	*Poaceae*	*Fragaria vesca* L.	*Luzula* sp.	*Hypericum* sp.	*Potentilla erecta* (L.) Raeusch	*Viola* sp.	*Lamiaceae*	*Montia fontana* L.	cf. *Jasione montana* L.	*Carex* sp. – biconvex	*Carex* spp. – trigonus	*Juncus* sp.	*Leaf scars*	*Fern* (leaf fragments)	*Moss*	*Bud scales*	*Buds*	*Dicot.* (leaf fragments)	*Monocot.* remains
009															+	+	+					+											+			+				+
013																										+			+			+	+			+			+	+
013b			14																														80+				1	51		
013.1	3		23	6	3							3		2		22		24	1	47	10						1			1			2	1	1	+	20	4		
016												2	2									+														+			+	+
019		+		+					+		+				+		+		+														+			+			+	
024	+		+												+	+	+											+					+			+		+		
047								1																																
049				1						4																									+	+	6			
049b							4			3																														
050						1	2	1		10		3											1	1									3			+				
051																																			1					
052										3														1	1	1					1	3	3							
053										2																														

yielded a relatively high pollen count, are higher when compared to those within the hilltop peat (Mighall & Chambers, 1993*a*) suggesting that a sizeable proportion of any woodland was confined to the valley sides and floor.

Woodland cover does not appear to have been adversely affected by mining as the total arboreal pollen percentages in the mine sediments do not fall, reaffirming the contention that Bronze Age mining at Copa Hill did not result in the permanent removal of woodland (Mighall & Chambers, 1993*a*). Post-mining sediment, for example stratigraphic units 058 and 013d, also contain relatively high numbers of arboreal pollen suggesting that a sizeable amount of woodland persisted in the Ystwyth valley after the cessation of Bronze Age mining on Copa Hill.

The palynological and plant macrofossil data also provides evidence for the exploitation of wood to use in the mine. Abundant twigs of *Corylus avellana* (Table 4), assemblages of cut, stripped and twisted fragments of branchwood and visible charcoal (Table 1) found in units 053, 052 and 050 confirms that hazel formed part of the local woodland. Hazel appears to have been collected and used by the miners for a variety of purposes including for rope, handles, baskets, brushwood flooring as well as firesetting of the ore from the rockface. Abundant pollen and plant remains of *Corylus avellana*, *Quercus*, *Alnus* and *Salix* were also found in prehistoric mine sediments. The discovery of large amounts of oak charcoal (this comprised more than 90% of the wood fuel used—Nayling, pers. comm.) and oak and alder timbers, including several wooden drains or launders such as the one preserved within the mine entrance sediments (049, 049b, 050, 053, 054, 055) and others within the base of the opencast (100, 081, 058), when combined with the palaeoecological data, supports the idea that the miners exploited these trees (Timberlake, 1995, 1996*a*; Mighall & Chambers, 1993*a*).

Radiocarbon dating of charcoal, wood and organic sediments suggests that prehistoric mining ceased at Copa Hill by approximately 1700–1650 BC. The mine appears to have been largely abandoned allowing the hole opened up by the miners to infill with sediment. Radiocarbon dates from sections E1 and E2 confirms that at least 6 metres of sediment accumulated between the Early Bronze Age and Early Mediaeval period. Approximately 4 m of this consisted predominantly of organic-rich sediment has accumulated between the base of 013f and the top of 012a from about 3400–1780 years BP. Compared with the hilltop peat analysed by Mighall & Chambers (1993*a*), this sedimentary sequence provides a better resolution for reconstructing the vegetation changes during this part of the late Holocene. These changes are summarized in Table 7.

The permanent loss of woodland from the Ystwyth valley, occurred during the Bronze Age and possibly into the Iron Age. Two phases of woodland clearance occur in stratigraphic unit 013b as arboreal pollen percentage falls from 30–25 cm and from 15–10 cm (Figure 6). Further non-permanent perturbations in arboreal pollen percentages, associated with peaks in microscopic charcoal, occur throughout stratigraphic unit 013.1 (Figure 7). The most significant reduction in the total arboreal percentage takes place during the accumulation of unit 013/012b. At the base of this

Table 5. Fossil insect remains for the stratigraphic units analysed in this study. The minimum number of individuals found is listed

(a)

	Sample number						
Species	9	12b	13b	13.1b	19	Category	
Carabidae							
Cychrus caraboides (L.)				1		W(d)	
Leistus monatnus Steph.			1			GHR	
L. terminatus (Hellw.)	1	1		2	4	W(m)	
Notiophilus spp.	1	2				GHR	
Loricera pilicornis (F.)	2					E(h)	
Dyschirius globosus (Hbst.)	1					GHR	
Trechus rivularis (Gyll.)	1					N-A	
T. quadristriatus Schr.				1	1	E	
T. obtusus Er.	2				1	E(h)	
Bembidion properans Steph.	1					GHR	
B. guttula (F.)			1			E(h)	
Bembidion sp.				1		U	
Bradycellus harpalinus (Serv.)				1		GHR	
Pterostichus (Poecilus) cupreus (L.)			1			E(h)	
P. strenuus (Panz.)					2	N-A	
P. diligens (Strm.)	3			1		E(h)	
P. nigrita (Payk.)/rhaeticus Heer	2			1		E(h)	
P. minor (Gyll.)	1					N-A	
P. oblongopunctatus F.				6	1	W	
P. angustatus (Duft.)				1		GHR(fire)	
P. niger (Schall.)				1	1	W(dw)	
P. melanarius (Ill.)			1			GHR	
P. aethiops (Panz.)				3		GHR	
Pterostichus spp.	1	2	1	1	1	U	
Abax parallelepipedus Pil	1		1			W	
Calathus fuscipes (Goez.)	3	1				GHR	
C. micropterus (Duft.)	1	2				W	
C. melanocephalus (L.)		1				GHR	
Agonum ericeti (Panz.)				1		A	
A. micans Nic.					1	N-A	
A. fuliginosum (Panz.)				1		N-A	
A. thoreyi Dej.	1					N-A	
Agonum sp.			1	1		U	
Amara lunicollis Schdte.				1		GHR	
Amara aenea (Deg.)				1		GHR	
Carabidae indet					2	U	
Dytiscidae							
Hydroporus tristis (Payk.)	26					A	
H. palustris (L.)	1					N-A	
H. pubescens (Gyll.)	14					Aq	
Hydroporus spp.	9	6	3		7	Aq	
Agabus bipustulatus (L.)	26	1	2	3	4	Aq	
Agabus sp.			1			Aq	
Gyrinidae							
Gyrinus spp.			2	2	1	Aq	
Hydraenidae							
Hydraena britteni Joy	31	27	3	6	4	N-A	
H. gracilis Germ.	1					N-A	
Limnebius truncatellus (Thun.)	1		2		1	Aq	
Hydrophilidae							
Helophorus grandis Ill.	4		1			N-A	
H. flavipes (F.)		1				A	
Helophorus spp.	7	9	3			Aq	
Cercyon sp.	2		1	1	1	F	
Hydrobius fuscipes (L.)	3		2	4	2	N-A	
Anacaena globulus (Payk.)	16				3	Aq	
Anacaena spp.			2	9		Aq	
Hydrophilidae indet					1	Aq	
Histeridae							
Histeridae indet.			1			Aq	
Silphidae							
Nicrophorus sp.				1		F(cfud)	
Oiceoptoma thoracicum (L.)				1		W	
Silpha obscura L.	1					GHR	
S. atrata L.	1		1	11	4	W(w)	

Table 5. Continued

(b)

	Sample number						
Species	9	12b	13b	13.1b	19	Category	
Catopidae							
Choleva angustata (F.)					1	E	
Catops nigricans (Spnc.)					1	F(crvd)	
Catops sp.			1			E	
Leiodidae							
Agathidium atrum (Payk.)					1	F(rvfu)	
Agathidium sp.				1		F	
Leiodidae indet				1		F(fu)	
Scymaenidae							
Stenichnus collaris (Müll.)					1	W(fu)	
Staphylinidae							
Micropeplus staphylinoides Marsh	1					F(rv)	
Proteinus sp.			1			U	
Eusphalerum minutum (F.)	1					N-A	
E. luteum (Marsh.)					4	W(d)	
Anthobium unicolor (Marsh.)			1	1		W(rv)	
Olophrum piceum (Gyll.)	4		6	16	11	N-A	
Olophrum sp.				1		E(w)	
Acidota cruentata (Mann.)			3	1	3	W	
Lesteva punctata Er.				1	2	N-A	
L. heeri Fauv.	1					E(w)	
Lesteva longoelytrata Goez.	1		1		1	N-A	
Lesteva spp.			6	14	1	E(w)	
Syntomium aeneum (Müll.)					2	W(d)	
Anotylus sculpturatus (Grav.)	2			2	1	D	
Anotylus sp.		1				D	
Oxytelus fulvipes Er.					3	N-A	
Stenus spp.	17	13	9	25	5	E(h)	
Medon sp.			1			E	
Lathrobium spp.	2	2	10	7	2	E(h)	
Xantholinus linearis (OI.)	6				2	E	
Othius angustus Steph.	2				4	E	
O. myrmecophilus Kies.			1			W(m)	
Othius sp.				2		E	
Philonthus splendens (F.)					1	D	
Platydracus fulvipes (Scop.)					1	D	
Ocypus brunnipes F.				1		E	
Quedius fuliginosus (Grav.)/curtipennis				1	3	E(h)	
Q. tristis (Grav.)	1					E	
Q. molochinus (Grav.)	1					E(h)	
Q. nemoralis Baudi			1			W(m)	
Quedius spp.	1	2	2	8	3	U	
Mycetoporus sp.	1					E(h)	
Tachinus proximus Kr.			1			F	
T. signatus (Grav.)					1	F	
T. elongatus Gyll.			1	1		F	
Autalia impressa (OI.)					1	F	
Falagria sp.					1	F	
Liogluta granigera (Kies.)					2	W(d)	
Tinotus morion (Grav.)					2	D	
Aleocharinae gen. indet	2		2	2	1	E(h)	
Staphylinidae indet		1		3		U	
Pselaphidae							
Bryaxis curtisi (Leach)				1	1	W(w)	
Bryaxis sp.					1	E(h)	
Brachygluta fossulata (Reich.)			1			E(w)	
Pselaphidae indet				2		U	
Cantharidae							
Podabrus alpinus (Payk.)				3		W(d)	
Cantharis obscura L.	1					W(m)	
Cantharis sp.			1			U	
Rhagonycha testacea (L)				1		W(d)	
R. femoralis (Brul.)	1				1	W	
R. lignosa (Müll.)				1	1	W(r)	
Elateridae							
Dalopius marginatus (L.)	2					W(d)	
Agriotes pallidulus (Ill.)	2					E	
A. acuminatus (Steph.)				3	1	W(d)	
A. obscurus (L.)	1					GHR	
Agriotes sp.				1	1	E	

Table 5. Continued

(c)

Species	9	12b	13b	13.1b	19	Category	
Ctenicera cuprea (F.)	3					GHR	
Aplotarsus incanus (Gyll.)	1			2		W(m)	
Athous haemorrhoidalis (F.)	1					W(d)	
A. vittatus (F.)	1					W(d)	
Athous sp.		1				E	
Elateridae indet				1	1	U	
Byrrhidae							
Cytilus sericeus (Forst.)	1					E(h)	
Brachypteridae							
Brachypterus urticae (F.)	1					GHR	
Cryptophagidae							
Cryptophagidae indet					1	U	
Dascillidae							
Dascillus cervinus (L.)	3		1	2	1	GHR	
Scirtidae							
Cyphon sp.				8	2	E(h)	
Lathridiidae							
Lathridius sp.				1		F	
Corticarina sp.	1			1		U	
Colydiidae							
Cerylon histeroides (F.)			1	1		W(rX)	
Coccinellidae							
Coccinella septempunctata L.	1					GHR	
Anobiidae							
Anobiidae gen indet				1		W	
Geotrupidae							
Geotrupes stercorosus (Scrib.)	1		1	1		D	
Geotrupes sp.					1	D	
Scarabaeidae							
Aphodius rufipes (L.)	1					D	
A. depressus (Kug.)				1		D	
A. contaminatus (Hbst.)		2		1		D	
A. sphacelatus (Panz.)			1	1		D	
A. fasciatus (OI.)			1			D	
Aphodius spp.		2	1	2		D	
Serica brunnea (L.)	1	1				GHR	
Phyllopertha horticola (L.)		1		2	1	GHR	
Chrysomelidae							
Plateumaris discolor (Panz.)/sericea (L.)				1	1	E(w)	
Chrysolina staphylaea (L.)				1	1	GHR	
Phaedon armoraciae (L.)				1		N-A	
P. tumidulus (Germ.)			1			GHR	
Phaedon sp.					1	GHR	
Phyllotreta consobrina (Curt.)	1					GHR	
Altica lythri Aube						GHR	
Chaetocnema concinna (Marsh.)	1		1	1		GHR	
C. hortensis (Fourc.)	2					N-A	
C. sahlbergi (Gyll.)	1					COASTAL	
Apteropeda orbiculata (Marsh.)					1	E	
Apteropeda sp.	1					E	
Psylliodes napi (F.)					1	GHR	
Chrysomelidae indet.				2	1	U	
Scolytidae							
Xyloterus domesticus (L.)				2		W(rXm)	
Curculionidae							
Rhynchites tomentosus Gyll.			1			W(*S*)	
R. aeneovirens (Marsh.)				3	2	W(*Q*)	
Deporaus betulae (L.)				1		W(*B*)	
Apion (Pirapion) immune Kirby					1	GHR	
Apion sp.	1			1		GHR	
Phyllobius viridiaeris (Laich.)				1		GHR	
P. roboretanus Gred.	180					GHR	

Table 5. Continued

(d)

Species	9	12b	13b	13.1b	19	Category	
			Sample number				
P. glaucus (Scop.)	1			1		W(d)	
P. maculicornis Germ.			1	5		W(d)	
P. argentatus (L.)				5	1	W(d)	
P. pyri (L.)	1					W(d)	
Phyllobius sp.			1			W	
Phyllobius / Polydrusus spp.				2		W	
Liophloeus tessulatus (Müll.)					1	W(*BQS*)	
Sciaphilus asperatus (Bonsd.)				2		E(h)	
Barypeithes sp.	1			2	1	GHR	
Strophosoma melanogrammum Forst.				1		W(m)	
S. capitalatum (Deg.)					1	W(m)	
S. sus Steph.				1		A	
Strophosoma sp.			1			A	
Barynotus squamosus Germ.	1		1			GHR	
Sitona spp.			4	1		GHR	
Notaris sp.				1		GHR	
Anthonomus rubi (Hbst.)	1					GHR	
Leiosoma deflexum (Panz.)					2	N-A	
Rhinoncus bruchoides (Hbst.)					1	E(h)	
Micrelus ericae (Gyll.)	1			6		A	
Ceuthorhynchidius troglodytes (F.)	1					GHR	
Ceuthorhynchidius spp.			1	9		GHR	
Ceutorhynchidius indet				5		GHR	
Milarus sp.				2		GHR	
Rhynchaenus sp.		1				W	
Rhamphus pulicarius (Hbst.)			3	2	1	W(*BS*)	
Curculionidae indet	5		3	3	1	U	
Total number of individuals	430	80	104	251	134	999	
Total number of species	77	22	55	91	74	196	
Formicidae							
Formicidae indet.	117	8	5	107	2		

A - Acidic wetland, Aq - Aquatic, *B* - *Betula*, D - Dung, E - Eurytopic, E(h) - Euryhygric, E(w) - Wetland, F - Wet/foul, GHR - Grassland/heathland/ruderal, NA - Non-acidic wetland, *Q* - *Quercus*, *S* - *Salix*, U - Unclassified, W - Woodland, W(d) - Deciduous woodland, W(w) - Damp woodland, X - Saproxylic, c - carrion, d - dung, fu - fungi, m - mixed, r - rotting, v - vegetation

stratigraphic unit the total arboreal pollen percentage is close to 50% TLP but by the top of the unit it has fallen to well below 20% TLP (Figure 8, Table 7). A similar reduction is implied from the beetle data, in units 013b and 013.1b (underlying 013) the woodland species comprise 12·5% and 24·7% respectively of the beetles that could be classified into ecogroups, but in unit 012b woodland species have been reduced to 5% (Figure 11). With virtually every fall in total arboreal pollen recorded there is evidence for agricultural activity including cereal-type pollen and a suite of taxa with cultural affinities, such as *Artemisia*, Lactuceae indet., *Plantago lanceolata*, *Rumex acetosa/acetosella* and *Potentilla*-type (Bonhcke, 1988). Fragments of dung beetles in stratigraphic unit 013/012b confirm that the land was being grazed (Tables 5 and 7). The peaks in microscopic charcoal that accompany the changes in the pollen record suggest that woodland may have been deliberately burnt. Stratigraphic unit 019 also provides evidence for agriculture although the arboreal pollen curves indicate that woodland remained unaltered (Figure 9). Total arboreal pollen percentages remain fairly constant at around 20% TLP throughout stratigraphic unit 012a suggesting that there were no further reductions in local woodland during the Roman occupation (Figure 10).

The vegetational changes reconstructed from the Copa Hill mine palaeoecological data is also characteristic of other parts of upland Wales. Permanent removal of woodland cover, the expansion of grasslands and peat development was taking place throughout the uplands of mid and south Wales during the late Holocene (Caseldine, 1990). The two closest sites to the Ystwyth are at the head of the Elan valley to the east and Plynlimmon to the north (Figure 1d). Moore & Chater (1969) suggest that phases of woodland clearance and regeneration occurred during the Bronze Age at each site but there are no radiocarbon dates for either profile. At Cefn Gwernffrwd, peat expanded over areas cleared of woodland during the Bronze Age between 3335 ± 80 and *c.* 2755 years BP (Chambers, 1982*a*). Wiltshire & Moore (1983) attribute major changes in vegetation at Pwll-nant-ddu in central Wales to the activity of Bronze Age cultures. Peat development has also been linked to woodland clearance and agriculture during the Bronze Age at Cefn

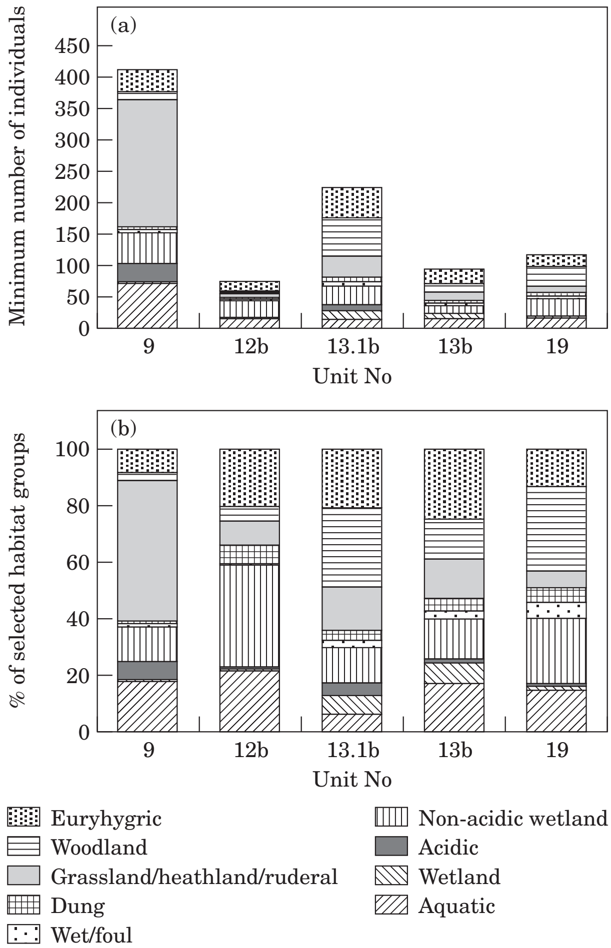

Figure 11. (a) Chart showing the actual proportions of each habitat group for the fossil coleoptera and (b) chart showing the relative proportions of each habitat group for the fossil coleoptera.

Table 6. Chemical data from selected stratigraphic units from the Bronze Age mine at Copa Hill

	Concentrations (μg g^{-1})		
Stratigraphic unit	Cu	Zn	Pb
Sections A, F, G			
041	858·3	819·2	117
042	599·5	844·7	90·8
046	4498·5	104	103·24
049	3359·2	2364·3	103·4
050	9865·8	14322·0	134·2
051	7818·2	11612·1	121
051b	7848·8	8511·6	151·2
052	633316·6	4688·0	228·3
052	4153·6	987·5	203·8
053	8882·7	5173·2	134·1
053	10,260·6	6198·3	162·9
053	17,807·6	106,608·2	297·0
054	20,529·8	10,242·8	110·4
054b	15,947·5	14,387·7	247·8
054a	10,125·0	1666·6	125
055	8632·0	5649·8	300·95
056	4250·7	374·64	216·14
Section D			
036	2593·5	6906·9	81
036	1720·5	1537·6	150·5
Section E1–E3			
058 (36 cm)	4498·6	348·2	208·9
058 (32)	6605·63	366·19	323·94
058 (28)	4538·9	374·63	158·5
058 (20)	5028·65	300·85	157·6
058 (16)	4219·8	420·6	230·6
058 (12)	4498·6	348·2	208·9
058 (8)	6218·1	424·9	212·46
058 (4)	4723	600	184·61
059	278·55	348·19	194·98
060	3843·9	4028·37	156·03
061	1525·4	1271·2	211·86

Depth of sample in parentheses.

Ffordd (Chambers, 1982*b*). In south Wales, Bronze Age people are linked to the loss of tree cover at Coed Taf around 3000 BP (Chambers, 1983) and woodland disturbance at Waun Fach South and Gader Fawr in the Black Mountains (Price & Moore, 1984; Moore, Merryfield & Price, 1984). Open grass-heath moor and blanket peat formation also occurred in the Cleddau valley during this period (Seymour, 1985). The expansion of acidic grassland and peat in and around the Ystwyth valley is suggested by changes in the pollen, plant macrofossil and fossil insect records outlined in Table 7.

All stratigraphic units measured for Cu exceed the natural background concentrations of 17·3 μg g^{-1} in local peat (Mighall *et al.*, 2001) and the average concentration of the Earth's crust of 50 μg g^{-1} (Wild, 1993). Pb and Zn concentrations also appear to be enriched. Pb concentrations exceed the geometric mean of 30 μg g^{-1} for soils in England and Wales (Reaves & Berrow, 1984), average continental crust concentrations of 14·8 μg g^{-1} (Wedepohl, 1995) and 42 μg g^{-1} determined in soils from a neighbouring valley unaffected by mining (Alloway & Davies, 1971). Zinc concentrations exceed average continental crust concentrations of 52 μg g^{-1} (Wedepohl, 1995) and background soil concentrations of 30–60 μg g^{-1} as suggested by Salomons & Forstner (1984), Macklin (1992) and Eklund & Håkansson (1997).

Cu concentrations in the sediments associated with Bronze Age mining support the proposition that Cu ore was being mined (Table 6). Crushing and processing of Cu (chalcopyrite) ore within the mine entrance area has enhanced Cu concentrations within the various layers of processing waste (Jenkins & Timberlake, 1997), especialy layers 046, 050–055 (see Figure 3e–g and Table 6). In stratigraphic unit 036, Cu concentrations occur between 1700 and 2600 μg g^{-1} whilst concentrations in unit 046 exceed 4000 μg g^{-1} but the highest concentrations are recorded in layers 050–055 (Table 6).

High Pb concentrations in layers 052–056 possibly result from the extraction of galena from the mine wall as areas of Pb mineralization occur in the rock where Cu ore is also found (Timberlake, 1996*a*). It is possible

Table 7. Pollen, microscopic charcoal, plant macrofossils and fossil insect characteristics for the stratigraphic units analysed in this study

Units	Characteristics	Interpretation
Section A, F, and G		
054–049	Total arboreal pollen percentages (%AP) average between 40 and 50% and are dominated by *Quercus*, *Corylus avellana*-type, *Alnus* and *Betula*. Plant remains of *Corylus avellana Quercus*, *Alnus* and *Salix* are present in most units. There are high Poaceae pollen percentages and taxa such as *Plantago lanceolata*, *Potentilla*-type, Ranunculaceae, *Rumex* and *Succisa* are recorded. Plant fragments such as *Juncus* sp., *Luzula* sp., *Hypercium* sp., *Carex* sp., *Potentilla erecta* (L.) Raeusch also feature. Moss fragments are also present in 050.	Mixed woodland with areas of damp grassland that is possibly grazed.
Section E1–E2		
013f	%AP in this unit are characterized by high *Quercus*, *Corylus avellana*-type and *Betula*. Poaceae pollen dominates the total non-arboreal pollen percentage (%NAP).	As above.
058	%AP averages between 48 and 50% in this unit and is dominated by *Quercus* and *Corylus avellana*-type pollen. High Poaceae pollen percentages and taxa such as *Plantago lanceolata*, *Rumex* spp. Lactuceae indet, *Potentilla*-type are present. Microscopic charcoal concentrations are also a feature of this unit.	Mixed woodland with areas of open, grazed grassland.
013d	%AP are characterized by high *Quercus*, *Corylus avellana*-type and *Betula*. Poaceae pollen dominates the %NAP.	As above.
013b	*Betula* female cone-scales and *Salix* sp. plant remains were found in this sediment. %AP, characterized by *Betula, Quercus* and *Corylus avellana*-type, initially exceeds 50% then decreases at 34 cm and 14 cm. High Poaceae percentages and the occasional cereal-type pollen are recorded in this unit. *Juncus* sp. dominate plant remains. Microscopic charcoal peaks occur at 38 and 6 cm. The insects include the weevils *Rhamphus pulicarius* (Hbst.) which feeds on Betulaceae and Salicaceae (Morris, 1993) and *Rhynchites tomentosus* (Gyll.) which feeds on Salicaceae; the wetland species *Hydrobius fuscipes* (L.), *Olophrum piceum* (Gyll.) and *Lesteva longoelytra* (Goez.); and the grassland/ruderal species *Phaedon timidulus* (Germ.) and *Chaetocnema concinna* (Marsh.).	Mixed woodland with areas of open, acidic grassland, possibly grazed. Some arable land. Blanket peat formation on valley plateau.
013.1	*Betula* sp. including female cone-scales, *Quercus*, *Alnus* and *Salix* plant macrofossils occur in unit 013.1. %AP percentages, characterized by *Betula*, *Quercus* and *Corylus avellana*-type, fluctuate around 50% AP with slight perturbations at 38 cm, 24 cm, 14 cm and 8 cm. The beetle species confirm the presence of *Betula*, *Quercus* and *Salix* as they include *Deporaus betulae* (L.), *Rhynchites aeneovirens* (Marsh.) and *Rhamphus pulicarius* as well as many common components of a woodland biota such as *Bryaxis curtisi* (Leach), *Rhagonycha lignosa* (Müll), *Pterostichus oblongopunctatus* (F.) and *Cerylon histeroides* (F.). Microscopic charcoal peaks occur at 22–20 cm and at 6 cm. This may explain the presence of *Pterostichus angustatus* (Duft.) as it is attracted to burnt ground (Bilton, 1991). High Poaceae percentages and the regular occurrence of cereal-type pollen is a feature of this unit. The grassland and ruderal beetle species include *Phyllopertha horticola* (L.), *Chrysolina staphylaea* (L.), *Phyllobius viridicollis* (F.) and *Chaetocnema concinna*. Dung beetles make up 3% of the sample: species such as *Aphodius contaminatus* (Hbst.), *A. sphacelatus* (Panz.) and *Anotylus sculpturatus* (Grav.) indicate grazing by large herbivores. Plant macrofossils remains include a large amount of Poaceae, *Calluna vulgaris* L. (Hull) and *Vaccinium myrtillus* L. This unit contained greatest variety of beetle species that are commonly found amongst *Calluna* including *Bradycellus harpalinus* (Serv.), *Amara lunicollis* (Schdte.), *A. aenea* (Deg.), *Strophosoma melanogrammum* (Forst.), *S. sus* (Steph.) and *Micrelus ericae* (Gyll.).	Mixed woodland present. Evidence for arable cultivation and grazing. Possible deliberate burning of woodland. Blanket peat continues to develop.
013/012b	%AP percentage falls gradually throughout this unit whilst woodland species comprise only 5% of the insect sample. Poaceae percentages remain above 40% TLP whilst cereal-type pollen is recorded between 110 and 105 cm and in the uppermost 35 cm. *Calluna*, Cyperaceae, *Potentilla*-type, Rubiaceae and *Plantago lanceolata* percentages all increase, especially from 20 cm. Aquatic and wetland species predominate, particularly *Hydraena britteni* (Joy) which is often found in bog pools (Merritt, 1995), *Helophorus* spp. and *Hydoporus* spp. Species common in grassland and heathland such as *Serica brunnea* (L.), *Calathus melanocephalus* (L.), *C. fuscipes* (Goez.) and *Phyllopertha horticola* are consistent with the large amount of Poaceae pollen. Dung species such as *Aphodius* and *Anotylus* spp. again suggest that the ground was being grazed by large herbivores. Microscope charcoal values peak at 44 cm and 36 cm.	Declining woodland cover is replaced by acidic grassland and blanket peat. Evidence for arable land and pasture.
019	%AP, characterized by *Betula*, *Quercus* and *Corylus avellana*-type, fluctuates around 45–50% TLP. Woodland insect species include those associated with *Betula*, *Quercus* and *Salix* such as *Liophloeus tessulatus* (Müll), *Rhamphus pulicarius* and *Rhynchites aeneovirens*. The Carabidae include many that are associated with deciduous woodland such as *Pterostichus strenuus* (Panz.), *P. oblongopunctatus*, *P. niger* (Schall.) and *Trechus obtusus* (Er.). High Poaceae percentages and the regular occurrence of cereal-type pollen and Pteropsida (monolete) indet. spores are a feature of this unit but there are few insect species associated with grassland. This unit is not dominated by insect species from any one habitat, although there are large numbers of woodland and wetland species.	Mixed woodland still present. Possible expansion of blanket peat. Pasture and arable land being used.

Continued

Table 7. Continued

Units	Characteristics	Interpretation
012a	%AP, characterized by *Corylus avellana*-type, remain well below 25% TLP. High percentages of *Calluna*, Cyperaceae and Poaceae characterize this unit. Rubiaceae and *Plantago lanceolata* are also well represented. Microscopic charcoal values peak at 10 cm.	Decreased woodland cover coincides with an expansion of acidic grassland and blanket peat.
09	This unit contains 19 insect species which are typical of rough unimproved grassland similar to that pertaining today. *Phyllobius roboretanus* (Gred.), a phytophagous weevil feeding mainly on herbaceous flora common in open grassland (Morris, 1997), is abundant. Woodland species comprised only 3% of the sample suggesting a similar landscape to that reflected by unit 012b. Large numbers of wetland/aquatic species were retrieved indicating the wetland insect community was flourishing on a blanket mire unaffected by contemporary land use. The plant macrofossil data from 009 supports the interpretation of the fossil Coleoptera as *Calluna vulgaris* and Poaceae remains were recovered.	Landscape dominated by open, acidic grassland and blanket peat. A small amount of woodland is still present locally.

that the miners also deliberately extracted small amounts of galena. Bick (1999) suggests that Pb and/or silver (Ag) were used for purposes such as abrasives, pigments, cosmetics or decoration. Whilst geochemical evidence from the hilltop peat on Copa Hill provides evidence of high concentrations of Cu rather than Pb coinciding with the known prehistoric tenancy of the mine, there is some evidence for the extraction of a limited amount of Pb (Mighall *et al*., 2000).

Whilst the Cu and Pb concentrations in the prehistoric mine sediments can be explained in terms of waste generated during mining, high concentrations of all three metals occur in sediments that post-date the prehistoric mining, for example, parts of stratigraphic units 013b, 013.1, 013/012b and 012.a (Figures 6–8, 10). However, unequivocal evidence for mining in the Ystwyth valley since the cessation of prehistoric mining approximately 3100 years BP up until Roman times is scant, although there is evidence of the Romans occupying this part of mid-Wales. Timberlake (1990) suggests that Roman or pre-Mediaeval hushing or mining may have occurred on the Comet Lode and some small-scale opencast mining may have taken place a short distance to the north on the Kingside lode (Timberlake & Mighall, 1992). A zone of Pb enrichment in the hilltop peat on top of Copa Hill does occur within the section ascribed to the Roman occupation providing additional evidence to support this theory. In contrast, Pb concentrations in stratigraphic unit 012.a dated to Roman times show no detectable increase (Figure 10). In fact the concentrations are comparable to those determined in some of the older sediments.

Human activity also cannot account for high concentrations of Zn. Zn was not intentionally exploited in prehistory although it was introduced into Cu before Roman times by smelting Cu and Zn ores together (Tylecote, 1976; Craddock, 1995). Roman metallurgists are thought to have used Zn in the form of calamine (Smithsonite ore; $ZnCO_3$) to make brass and other Cu-based alloys (Tylecote, 1976; Craddock, 1995), but there is no archaeological evidence of zinc ores being exploited in the Ystwyth valley. If any mining did take place Zn was not mined and/or processed in sufficient quantities to generate a pollution signal in the blanket peat accumulating on Copa Hill.

Because there is no firm archaeological evidence it is difficult to argue that the metal concentrations determined in stratigrapic units 013b, 013.1, 013/012b and 012a are related in any way to episodes of mining. It is more likely that the metal concentrations have been influenced by another factor. These include leaching, contamination by water carried into the mine from upslope, bioaccumulation by surface vegetation, sediment composition (% of organic matter, texture, degree of decomposition, mineralogy, particle size), redox potential and pH (Fanfani, Zuddas & Chessa, 1997; Gâbler, 1997; Gee *et al*., 1997). As the concentrations of Cu, Pb, and Zn in the mine sediments varies, it seems likely that one or more of these processes has been influential.

One possibility is the downward migration of metals atmospherically deposited as a result of later historical mining. The main phase of Ph-Zn mining in the Ystwyth valley commenced in the 1690s and continued intermittently until the early 1920s (Hughes, 1981). Cu, Zn and Pb, either as wind dispersed ore crushing material or as particulate matter derived from smelting, are possible sources to account for elevated concentrations via leaching. The extent of leaching and downward percolation of Cu, Pb or Zn at Copa Hill is unknown but the ancient drainage system employed by the Bronze Age miners and the presence of aquatic fossil insects suggests that the mine suffered from waterlogging, and ponding of water probably continued after the mine was abandoned, at least until the opencast was inadvertently drained as a result of the sinking of a prospection shaft through its base either at the end of the 18th century or the beginning of the 19th century (Timberlake & Mighall, 1992).

Acid mine drainage may well have contributed to the movement of metals down the mine and their re-deposition by precipitation in ochres (iron oxide/hydroxides). Chemical analysis of ochres from abandoned mines in mid-Wales has shown that they can contain higher concentrations of Cu, Pb and Zn than recorded in the Copa Hill mine sediments (Fuge *et al*., 1994). Drainage waters from the mid-Wales orefield, encompassing the Ystwyth valley, are heavily contaminated with metals. Analysis of adit effluent, spoil run-off and spoil drainage from the Ystwyth valley itself contain Cu, Pb and Zn showing that metals are being removed from the mine waste. In particular Zn and Pb are enhanced indicating that these metals are preferentially removed from mine waste compared to Cu (Fuge *et al*., 1991).

Once metals enter the mine sediments from whatever source, their retention is dependent upon sediment composition and there does appear to be a relationship between sediment composition and metal concentration in the Copa Hill mine. Organic sediments, such as stratigraphic units such as 058, 060, 012b/013, 013.1, 013b, are generally enriched in Cu. Cu concentrations exceed 1000 $\mu g\ g^{-1}$ in 013b, 500 $\mu g\ g^{-1}$ in 013.1 (Figures 6 and 7), and they are above 1000 $\mu g\ g^{-1}$ until the upper 15 cm of 012b/013 (Figure 8) where mineral matter and stones dominate sediment composition. The Cu peak in unit 012a at 10 cm coincides with a visible increase in organic matter content (Figure 10). The pattern of Zn enrichment is similar to that of Cu but Zn is present in much higher concentrations in the upper part of stratigraphic unit 013.1 and the lower part of 013. Cu and Zn have a large affinity towards organic matter (Shotyk, 1988) so the organic-rich sediments in the mine act as a sink to trap them as both metals have probably been scavenged from metal enriched groundwater to form stable, immobile organo-metal complexes (Livett, Lee & Tallis, 1979). Pb concentrations are much lower and they are probably controlled by other factors. A lack of scavenging and organic cation exchange sites possibly best explain the lower heavy metal concentrations in predominantly inorganic units (e.g. 046, 053, 056, 059, 061) where their retention will possibly result from their adsorption on to clay particle surfaces.

Weathering from highly mineralized bedrock and mine waste to produce metal-rich clay within the base of the prehistoric workings may also account for very high Zn concentrations contained in the basal units (e.g. 050–054, 058 and 060) (Table 6). Fanfani, Zuddas & Chessa (1997) showed that weathering processes can alter mine waste resulting in the relatively easy dissolution of Zn and intermediate removal of Pb. Similar processes may explain Pb concentrations and to a lesser extent, Zn compared with Cu. Pb concentrations may have been influenced by low pH and organic-rich waters that increase its solubility, and therefore its mobility (Shotyk, 1988), although recent research has shown that Pb is more immobile in peat than previously thought (Shotyk, Norton & Farmer, 1997).

Until new evidence for mining and/or smelting is discovered, it is suggested that natural processes and the contamination by historical mining pollution including metal-enriched water and atmospheric sources best explain the metal concentrations determined from the Copa Hill mine sediments. The record for Cu, Pb and Zn shows significant chronological differences with atmospheric pollution records from ombrotrophic hilltop peat located above the mine (Mighall *et al*., 2002, in press) and the known archaeological and historical evidence for metal mining in the Ystwyth valley.

Conclusion

The results presented in this paper suggest that informative palaeoecological data is preserved in mining sediments that may otherwise yield little in the way of typological and dateable artefacts normally associated with archaeological excavation. The recovery of pollen, charcoal, plant macrofossil and fossil insects from the prehistoric mine on Copa Hill has yielded evidence to support the archaeological record of mining. The reconstruction of vegetation history using pollen analysis, plant macrofossils and fossil insect remains provides an insight into the landscape, the available resources and resultant impact of prehistoric mining.

Whilst the chemical data produced expected high concentrations of Cu, Pb and Zn in prehistoric mine sediments it is clear that numerous factors influence metal concentrations making the interpretation of the chemical data complex. High Cu values recorded within the basal sediments appear to confirm that prehistoric mining was taking place. However, the existence of anomalously high metal concentrations in post mining sediments contrasts with off-site atmospheric pollution histories and known archaeological evidence. Other post depositional factors, such as leaching, weathering of waste and the bedrock, appear to have prevented a chronological record of past mining from being retained.

As with other historical mining and smelting sites, the metals still held within the mine sediments are potentially available and, if released, could contaminate surrounding soils and groundwater. The chemical and physical environmental conditions, especially in the organic units, appear to be acting as a store for Cu and, to a lesser extent, Zn but contamination of groundwater from such sources may continue as elements are slowly leached from the ancient workings and buried mine spoil.

Acknowledgements

Thanks are due to Mrs E. Turner and I. White for help with the chemical analyses and the Cartography Unit at Coventry University for help in producing figures and tables. Professor Paul Buckland kindly commented on an earlier version of this paper. We thank Dr M. Cressey and an anonymous referee for comments on the paper.

References

Alloway, B. J. & Davies, B. E. (1971). Trace element content of soils affected by base metal mining in Wales. *Geoderma* **5,** 197–208.

Ambert, P., Barge, H., Bourhis, J.-R., Esperou, J.-L., Houles, N. & Solari, M. E. (1990). *Cabrieres-Herault. Le plus vieux centre minier metallurgique de France (2500 av. J.-C.)*. Archeologie en Languedoc, Saint-Mathieu de Treviers, 20–22 Septembre, 1990.

Andrew, R. (1984). *A practical pollen guide to the British Flora*. Technical guide 1. Cambridge: Quaternary Research Association.

Armfield, C. (1989). Dressing floors on the Kingside lode, Copa Hill, Cwmystwyth. *Archaeology in Wales* **29,** 27–29.

Barber, K. E. (1976). History of vegetation. In (S. B. Chapman, Ed.) *Methods in Plant Ecology*. Oxford: Blackwell, pp. 5–83.

Bennett, K. D., Whittington, G. & Edwards, K. J. (1994). Recent plant nomenclatural changes and pollen morphology in the British Isles. *Quaternary Newsletter* **73,** 1–6.

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

Bilton, D. T. (1991). *Pterostichus angustatus* (Duftschmid) (Col., Carabidae) in Cumberland and Westmoreland. *Entomologist's Monthly Magazine* **127,** 118.

Birks, H. J. B. (1970). Inwashed pollen spectra at Loch Fada, Isle of Skye. *New Phytologist* **69,** 807–820.

Bonhcke, S. (1988). Vegetation and habitation history of the Callanish Area, Isle of Lewis, Scotland. In (H. H. Birks, H. J. B. Birks, P. E. Kaland & D. Moe, Eds) *The Cultural Landscape—Past, Present and Future*. Cambridge: Cambridge University Press, pp. 445–461.

Burnham, B., Burnham, H. & Walker, M. J. C. (1992). Excavations across the Annell and Gwenlais Leats, near Dolaucothi, in 1990. *Archaeology in Wales* **32,** 2–8.

Caseldine, A. E. (1990). *Environmental Archaeology in Wales*. Lampeter: St Davids University College.

Cernych, E. N. (1978). Aibunar—a Balkan copper mine of the fourth millenium BC. *Proceedings of the Prehistoric Society* **44,** 203–217.

Chambers, F. M. (1982*a*). Environmental history of Cefn Gwernffrwd, near Rhandirmwyn, Mid-Wales. *New Phytologist* **92,** 607–615.

Chambers, F. M. (1982*b*). Two radiocarbon-dated pollen diagrams from high altitude peats in south Wales. *Journal of Ecology* **70,** 445–459.

Chambers, F. M. (1983). Three radiocarbon-dated pollen diagrams from upland peats north-west of Methyr Tydfil, South Wales. *Journal of Ecology* **71,** 475–487.

Clark, R. L. (1982). Point count estimation of charcoal in pollen preparations and thin sections of sediments. *Pollen et Spores* **24,** 523–535.

Clark, S. H. E. (1997). *Copper & Coleoptera, Fossil Coleopteran Evidence for the impact on the Environment of Prehistoric Mining at Copa Hill, Cwmystwyth, Wales*. Unpublished M. Sc. thesis, Dept. of Archaeology & Prehistory, University of Sheffield.

Coope, G. R. & Osborne, P. J. (1968). Report on the Coleopterous Fauna of the Roman Well at Barnsley Park, Gloucestershire. *Transactions of the Bristol & Gloucestershire Archaeological Society* **86,** 84–87.

Craddock, P. T. (Ed.) (1980). *Scientific studies in early mining and extractive metallurgy*. British Museum occasional Paper 20. London: British Museum.

Craddock, P. T. (1994). Recent progress in the study of early mining and metallurgy in the British Isles. *Historical Metallurgy* **28**(2), 69–84.

Craddock, P. T. (1995). *Early mining and metal production*. Edinburgh: Edinburgh University Press.

Cushing, E. J. (1967). Evidence for differential pollen preservation in Late-Quaternary sediments in Minnesota. *Review of Palaeobotany and Palynology* **4,** 87–101.

Dörfler, W. (1995). Versuch einer Modellierung des Energieflusses und des Rohstoffverbrauchs während der römisch-kaiserzeitlichen Eisenverhüttung in Joldelund, Ldkr. Nordfriesland. *Probleme der Küstenforschung im südlichen Nordseegebiet* **23,** 175–185.

Dutton, A. & Fasham, P. (1994). Prehistoric copper mining on the Great Orme, Llandudno, Gwynedd. *Proceedings of the Prehistoric Society* **60,** 245–286.

Edwards, K. J. (1999). Palynology and People: observations about on the British record. In (K. J. Edwards & J. Sadler, Eds) *Holocene environments of prehistoric Britain*. Quaternary Proceedings 7, pp. 531–544.

Eklund, M. & Hâkansson, K. (1997). Distribution of cadium, copper and zinc emitted from a Swedish copperworks, 1750–1900. *Journal of Geochemical Exploration* **58,** 291–299.

Faegri, K., Kaland, P. E. & Krzywinski, K. (1989). *Textbook of pollen analysis* 4th edition. Chichester: John Wiley and Sons.

Fanfani, L., Zuddas, P. & Chessa, A. (1997). Heavy metals speciation analysis as a tool for studying mine tailings weathering. *Journal of Geochemical Exploration* **58,** 241–248.

Foster, I. D. L., Dearing, J. D., Charlesworth, S. M. & Kelly, I. A. (1987). Paired lake catchment studies: a framework for investigating chemical fluxes in small drainage basins. *Applied Geography* **7,** 115–133.

Fuge, R., Laidlaw, I. M. S., Perkins, W. T. & Rogers, K. P. (1991). The influence of acidic mine and spoil drainage on water quality in the mid-Wales area. *Environmental Geochemistry and Health* **13**(2), 70–75.

Fuge, R., Pearce, F. M., Pearce, N. J. G. & Perkins, W. T. (1994). The chemistry of iron oxide/hydroxide precipitates associated with acid drainage abandoned metal mines in Wales. *Environmental Geochemistry and Health* **16**(2), 93.

Gâbler, H-E. (1997). Mobility of heavy metals as a function of pH of samples from an overbank sediment profile contaminated by mining activities. *Journal of Geochemical Exploration* **58,** 185–194.

Gee, C., Ramsey, M. H., Maskall, J. & Thornton, I. (1997). Minerology and weathering processes in historical smelting slags and their effects on the mobilisation of lead. *Journal of Geochemical Exploration* **58,** 249–257.

Gilbertson, D. D., Grattan, J. P., Cressey, M. & Pyatt, F. B. (1997). An air pollution history of metallurgical innovation and iron and steel making: A geochemical archive of Sheffield. *Water, Air and Soil Pollution* **100,** 327–341.

Grimm, E. (1991–1993). *TILIA AND TILIA.GRAPH*. Illinois: Illinois State Museum.

Hughes, S. J. S. (1981). *The Cwmystwyth Mines*. British Mining Series Monograph no. 17. Sheffield: Northern Mine Research Society.

Hughes, S. J. S. (1994). The hushing leats at Cwmystwyth. In (T. Ford & L. Willies, Eds) *Mining Before Powder*. Historical Metallurgy Society Special Publication and Bulletin of The Peak District Mines Historical Society **12**(3), pp. 48–53.

Jenkins, D. A. (1988). Trace elements analysis in the study of ancient metallurgy. In (J. Ellis-Jones, Ed.) *Aspects of ancient mining and metallurgy*. Bangor: Acta of the British School at Athens, pp. 95–105.

Jenkins, D. A. (1995). Mynydd Parys copper mines. *Archaeology in Wales* **35,** 35–37.

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

Livett, E. A., Lee, J. A. & Tallis, J. H. (1979). Lead, zinc and copper analyses of British blanket peats. *Journal of Ecology* **67,** 865–891.

Lucht, W. H. (1987). Die Käfer Mitteleuropas, Katalog. Goecke & Evers, Krefeld.

Macklin, M. (1992). Metal pollution of soils and sediments: a geographical perspective. In (M. D. Newson, Ed.) *Managing* *human impact on the natural environment: patterns and processes*. London: Belhaven Press, pp. 172–195.

Marshall, P. D., O'Hara, S. L. & Ottaway, B. S. (1999). Early copper metallurgy in Austria and methods of assessing its impact on the environment. *Der Anschnitt* **00,** 255–264.

Merritt, R. (1995). Notable water beetles in Derbyshire: an interim review. *Sorby Record* **31,** 59–65.

Mighall, T. M., Abrahams, P. W., Grattan, J. P., Hayes, D., Timberlake, S. & Forsyth, S. (2001). Geochemical evidence for atmospheric pollution derived from prehistoric copper mining at Copa Hill, Cwmystwyth, mid-Wales, U.K.. *Science of the Total Environment* in press.

Mighall, T. M. & Chambers, F. M. (1993*a*). The environmental impact of prehistoric copper mining at Copa Hill, Cwmystwyth, Wales. *The Holocene* **3**(3), 260–264.

Mighall, T. M. & Chambers, F. M. (1993*b*). Early mining and metalworking: its impact on the environment. *Historical Metallurgy* **27,** 71–83.

Mighall, T. M. & Chambers, F. M. (1997). Early ironworking and its impact on the environment: palaeoecological evidence from Bryn y Castell hillfort, Snowdonia, north Wales. *Proceedings of the Prehistoric Society* **63,** 199–219.

Mighall, T. M., Grattan, J. P., Lees, J. A., Timberlake, S. & Forsyth, S. (forthcoming). An atmospheric pollution history for lead-zinc mining from the Ystwyth Valley, Dyfed, mid-Wales, UK as recorded by an upland blanket peat. *Geochemistry*.

Mighall, T. M., Timberlake, S., Grattan, J. P. & Forsyth, S. (2000). Bronze Age lead mining at Copa Hill—fact or fantasy? *Historical Metallurgy* **34,** 1–12.

Miller, D. (1995). 2000 years of indigenous mining and metallurgy in southern Africa—a review. *S. Afr. Tydskr. Geol.* **98**(2), 232–238.

Moore, P. D. & Chater, E. H. (1969). The changing vegetation of west-central Wales in the light of human history. *Journal of Ecology* **57,** 361–379.

Moore, P. D., Merryfield, D. L. & Price, M. D. R. (1984). The vegetation and development of blanket mire. In (P. D. Moore, Ed.) *European Mires*. London: Academic Press, pp. 203–235.

Moore, P. D., Webb, J. A. & Collinson, M. E. (1991). *Pollen Analysis*. 2nd edition. London: Blackwell Scientific Publications.

Morris, M. G. (1993). A review of the British species of Rhynchaeninae (Col., Curculionidae). *Entomologist's Monthly Magazine* **129,** 177–197.

Morris, M. G. (1997). *Broad-nosed weevils. Handbooks for the Identification of British Insects 5*, 17a. London: Entomological Society of London.

Nakagawa, T., Brugiapaglia, E., Digerfeldt, G., Reille, M., De Beaulieu, J.-L. & Yasunda, Y. (1998). Dense-media separation as a more efficient pollen extraction method for use with organic sediment/deposit samples: comparison with the conventional method. *Boreas* **27,** 15–24.

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

O'Brien, W. F. (1994*b*). Ross Island: the beginning. *Archaeology Ireland* **9,** 24–27.

Pott, R., Freund, H. & Speier, M. (1992). Anthropogenic changes of landscape by extensive woodland management and charcoal production in Seigerland (Northrhine-Westphalia, Germany). In (J. P. Metailie, Ed.) *Protoindustries et histoire des Forêts*. Toulouse: GDR ISARD-CNRS, pp. 163–176.

Price, M. D. R. & Moore, P. D. (1984). Pollen dispersion in the hills of Wales: a pollen shed hypothesis. *Pollen et Spores* **26,** 127–136.

Pyatt, F. B., Gilmore, G., Grattan, J. P., Hunt, C. O. & McLaren, S. (2000). An imperial legacy? An exploration of the environmental impact of ancient metal mining and smelting in southern Jordan. *Journal of Archaeological Science* **27,** 771–778.

Reaves, G. A. & Berrow, M. L. (1984). Total lead concentrations in Scottish soils. *Geoderma* **32,** 1–8.

Reille, M. (1992). *Pollen et spores D'Europe et D'Afrique du Nord. Editions du Laboratoire de botanique historique et palynologie*. Marseille.

Robinson, M. A. (1981). The Iron Age to Early Saxon environment of the Upper Thames terraces. In (M. Jones & G. D. Dimbleby, Eds) *The Environment of Man: The Iron Age to the Anglo-Saxon Period*. Oxford: British Archaeological Reports B87, pp. 161–164.

Roper, T. (1996). Fossil insect evidence for the development of raised mire at Thorne Moors near Doncaster. *Biodiversity & Conservation* **5,** 503–521.

Rosen, D. & Dumayne-Peaty, L. (2001). Human impact on the vegetation of south Wales during late historical times: palynological and palaeoenvironmental results from Cryfmlyn Bog NNR, West Glamorgan, Wales, UK. *The Holocene* **11**(1), 11–24.

Salomons, W. & Forstner, U. (1984). *Metals in the hydrocycle*. Berlin/New York: Springer-Verlag.

Schweingruber, F. H. (1990). *Anatomy of European woods*. Bern & Stuggart: Paul Haupt.

Seymour, W. P. (1985). *The environmental history of the Presli region of south-west Wales over the past 12,000 years*. Ph.D. thesis, University of Wales.

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

Shotyk, W., Norton, S. A. & Farmer, J. G. (1997). Summary of the workshop on peat bog archives of atmospheric metal deposition. *Water, Air and Soil Pollution* **100**(3&4), 213–219.

Stace, C. (1991). *New flora of the British Isles*. Cambridge: Cambridge University Press.

Stos-Gale, Z., Gale, N. & Papastamataki, A. (1988). An early Bronze Age copper smelting site on the Aegean Island of Kythnos II. In (J. Ellis-Jones, Ed.) *Aspects of ancient mining and metallurgy*. Bangor: Acta of the British School at Athens, pp. 11–22.

Stuiver, M. & Reimer, P. J. (1993). A computer program for radiocarbon age calibration. *Radiocarbon* **35,** 215–230.

Stuiver, M., Reimer, P. J., Bard, E., Beck, J. W., Burr, G. S., Hughen, K. A., Kromer, B., McCormac, F. G., v. d. Plicht, J. & Spurk, M. (1998). INTCAL98 radiocarbon age calibration 24,000–0 cal BP. *Radiocarbon* **40,** 1041–1083.

Timberlake, S. (1990*a*). Excavations at an early mining site on Copa Hill, Cwmystwyth, Dyfed 1989 and 1990. *Archaeology in Wales* **340,** 7–13.

Timberlake, S. (1990*b*). Excavations and fieldwork on Copa Hill, Cwmystwyth, 1989. In (P. Crew & S. Crew, Eds) *Early Mining in the British Isles*. Plas Tan y Bwlch Occasional Paper No. 1, 22–29.

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. Ford & L. Willies, Eds) *Mining Before Powder*. Historical Metallurgy Society Special Publication and Bulletin of The Peak District Mines Historical Society **12**(3), pp. 133–143.

Timberlake, S. (1995). Copa Hill, Cwmystwyth. *Archaeology in Wales* **35,** 40–43.

Timberlake, S. (1996*a*). Copa Hill, Cwmystwyth. *Archaeology in Wales* **36,** 60–61.

Timberlake, S. (1996*b*). Copa Hill, Cwmystwyth. *Archeology in Wales* **36,** 84.

Timberlake, S. (2001). Mining and prospection for metals in Early Bronze Age Britain—making claims within the archaeological landscape. In (J. Bruck, Ed.) *Bronze Age landscapes—tradition and transformation*. Oxford, Oxbow Books, pp. 179–192.

Timberlake, S. (2002*a*). Ore prospection during the Early Bronze Age in Britain. In (M. Bartelheim, E. Pernicka & R. Krause, Eds) *The beginnings of metallurgy in the old world*. Archaeometrie—FreibergerForschungen zur Altertumswissenschaft 1, in press.

Timberlake, S. (2002*b*). *Excavations on Copa Hill, Cwmystwyth (1986–1999)—an early Bronze Age copper mine within the uplands of central Wales.* British Archaeological Reports Oxford: Archaeopress, in press.

Timberlake, S. & Mighall, T. M. (1992). Historic and prehistoric mining on Copa Hill, Cwmystwyth. *Archaeology in Wales* **32,** 38–44.

Tylecote, R. F. (1976). *The prehistory of metallurgy in the British Isles*. London: The Institute of Metals, 257 pp.

Wedepohl, K. H. (1995). The composition of the continent crust. *Geochimica et Cosmochimica Acta* **59**(7), 1217–1232.

West, S., Charman, D. J., Grattan, J. P. & Cherburkin, A. K. (1997). Heavy metals in Holocene peats from south west England: detecting mining impacts and atmospheric pollution. *Water, Air, and Soil Pollution* **100,** 343–353.

Wild, A. (1993). *Soils and the Environment*. Cambridge: Cambridge University Press.

Wiltshire, P. E. J. & Moore, P. D. (1983). Palaeovegetation and palaeohydrology in upland Britain. In (K. J. Gregory, Ed.) *Background in Palaeohydrology*. Chichester: John Wiley & Sons, pp. 433–451.