A FURTHER PALAEOENVIRONMENTAL ASSESSMENT OF THE BLANKET PEAT SURROUNDING THE SOURCE OF THE SEVERN, PLYNLIMON, AND ITS WIDER CONTEXT

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METAL LINKS PROJECT

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1. INTRODUCTION

This paper presents new findings of a palaeoecological and geochemical study of a peat core sampled to reconstruct the environmental history at Plynlimon, Powys, central Wales. The work formed part of the *Metal Links: Forging Communities Together* InterReg IVA project which deals with mining communities in Wales (Mid-Wales and Anglesey) and Ireland (Glendalough and Copper Coast, County Waterford). The aims of the original research were threefold. Firstly, to reconstruct the vegetation and fire history from the peat core through the use of microfossil (pollen, non-pollen palynomorphs [fungal spores (NPPs)] and microscopic charcoal analysis. Secondly, to construct a chronology for the sequences using radiocarbon dating and thirdly, to reconstruct atmospheric dust and metal pollution histories using peat geochemistry. This report builds upon the previous study conducted by Mighall et al. in 2012 by presenting a new, improved chronology, a new set of geochemical data and an improved pollen diagram after the additional of more pollen and non-pollen palynomorph data.

The chosen sampling site (SOS) is located near Pumlumon Cwmbiga (SN82794 89889), close to the source of the River Severn (Figure 1 in Mighall et al., 2012). It is within a kilometre of the Bronze Age and 19th Century mine of Nantyreira (SN 826875), approximately 2 km from the 19th Century Eisteddfa Gurig mine (SN 796857), 2 km from the 19-20th century Nantiago Mine (SN 826864), 2.5-3 km from the 17-19th Century Siglenlas mine (SN 840864), 4 km from the Nantmelin Mine (SN 862878), 5 km from the Bronze Age working at Nantyricketts (SN 864867), and approximately 7 km from the 17-19th Century copper mine of Guefron (SN 886857) (Figure 2). Two of these sites, Nantyreira and Nantyricketts, have been already been investigated by Timberlake (1988, 1990, 1995).

2. METHODS

2.1 Geochemistry

A further set of samples from the original core analyzed, using a different method, especially to confirm the pattern of the lithogenic elements, and in particular, Pb and to generate a copper profile. Elemental composition of the peat was determined for the dried, milled and homogenized samples of either 2 or 2.5 cm thickness. Concentrations of major and trace lithogenic elements (Silicon (Si), aluminum (Al), titanium (Ti), iron (Fe), gallium (Ga), rubidium (Rb), and zirconium (Zr)), and trace metals and metalloids (lead (Pb), copper (Cu), chromium (Cr), zinc (Zn), nickel, (Ni) and arsenic (As)), and halogens (chlorine (Cl) and bromine (Br)) were obtained by X-ray fluorescence dispersive EMMA-XRF analysers (Cheburkin & Shotyk, 1996; Weiss et al., 1998). The instruments are hosted at the RIAIDT (Infrastructure Network for the Support of Research and Technological Development) facility of the University of Santiago de Compostela, Spain. Standard reference materials were used for the calibration of the instruments. Quantification limits were: 0.01% for Al, and Ti; 0.05% for Si; 0.5 µg g^{1} for Pb; 1 µg g^{-1} for the other trace elements. Replicate measurements were taken for one every five samples in order to account for reproducibility; all replicates were within 5% agreement.

2.2 Dating

1. ^{210}Pb: To provide a highly-resolved chronology for the last 100 to 120 calendar years, the unsupported ^{210}Pb activity within samples towards the peat surface was ascertained. ^{210}Pb and ^{214}Pb activities were measured using EG&G ORTEC hyper-pure Germanium detectors in a well configuration (11 mm diameter, 40 mm depth) housed at Coventry University. The method for assessing the amount of unsupported ^{210}Pb is described by Appleby & Oldfield (1978), and Appleby (2001). A CRS model was used to calculate ages as accumulation rates varied along the core (Appleby et al., 1988).
2. ^{14}C: an additional sample from 172-173 cm deep in the peat core was sent to Poznan Radiocarbon Laboratory for analysis by AMS.

2.3 Microfossils

Additional samples (10, 140, 148, 164, 180, 188, 198 and 206 cm) of *c*. 2g wet weight and 0.5cm thickness were prepared for pollen, non-pollen palynomorphs (NPPs) and microscopic charcoal analyses using the procedure described by Barber (1976). At least 500 land pollen grains were counted for each sub-sample. Pollen identification was made using the identification keys from Fægri *et al*. (1989), Moore *et al*. (1991) and a pollen type slide collections housed in the University of Aberdeen. When possible, cereal-type pollen was differentiated from wild grass pollen based on grain size, pore and annulus diameter and surface sculpturing (Andersen, 1979). Pollen preservation was recorded following Cushing (1967) and each pollen grain was classified as broken, corroded, crushed or degraded. Pollen grains that had no remaining distinguishing features were categorised as unidentified. NPPs were recorded during routine pollen counting and they were identified using the descriptions and photomicrographs of van Geel (1978), van Geel *et al.*, (1989; 2003) and van Geel and Aptroot (2006).

3. RESULTS

3.1 Dating: The results are shown in Table 1 with 2 σ calibrated age ranges (in calibrated years BC/AD). All dates appearing in the following text are cited in calendar years BC/AD, unless otherwise stated, and are the 95% confidence intervals derived from the model, with end-points rounded to the nearest decade.

The CLAM software package (Blaauw, 2010) was used, combining ^{14}C and ^{210}Pb ages, to create an age-depth model to infer approximate ages for all levels. The age-depth model is shown in Fig. 1. A revised assignation of the main archaeological periods based on the improved age-depth model is shown in figure 4. In the new scheme, the Bronze Age ends at *c*. 178 cm, the Iron Age ends at *c*. 155 cm, the Roman period occurs between 155 and 141 cm, more peat accumulated during the Dark Ages compared to the original scheme presented in Mighall et al. (2012) whereas the boundaries of the medieval and post medieval periods see little change.

Table 1: Radiocarbon dates from the SOS site.

Sample depth (cm)	Lab no.	Age ^{14}C BP	Calibrated Age
90-92	Poz-45839	770±30	Cal AD 1217- 1281
172-173	Poz-58769	2400±30	Cal BC 730-399
200-202	Poz-45840	3360±35	Cal BC 1740-1603; 1588- 1534

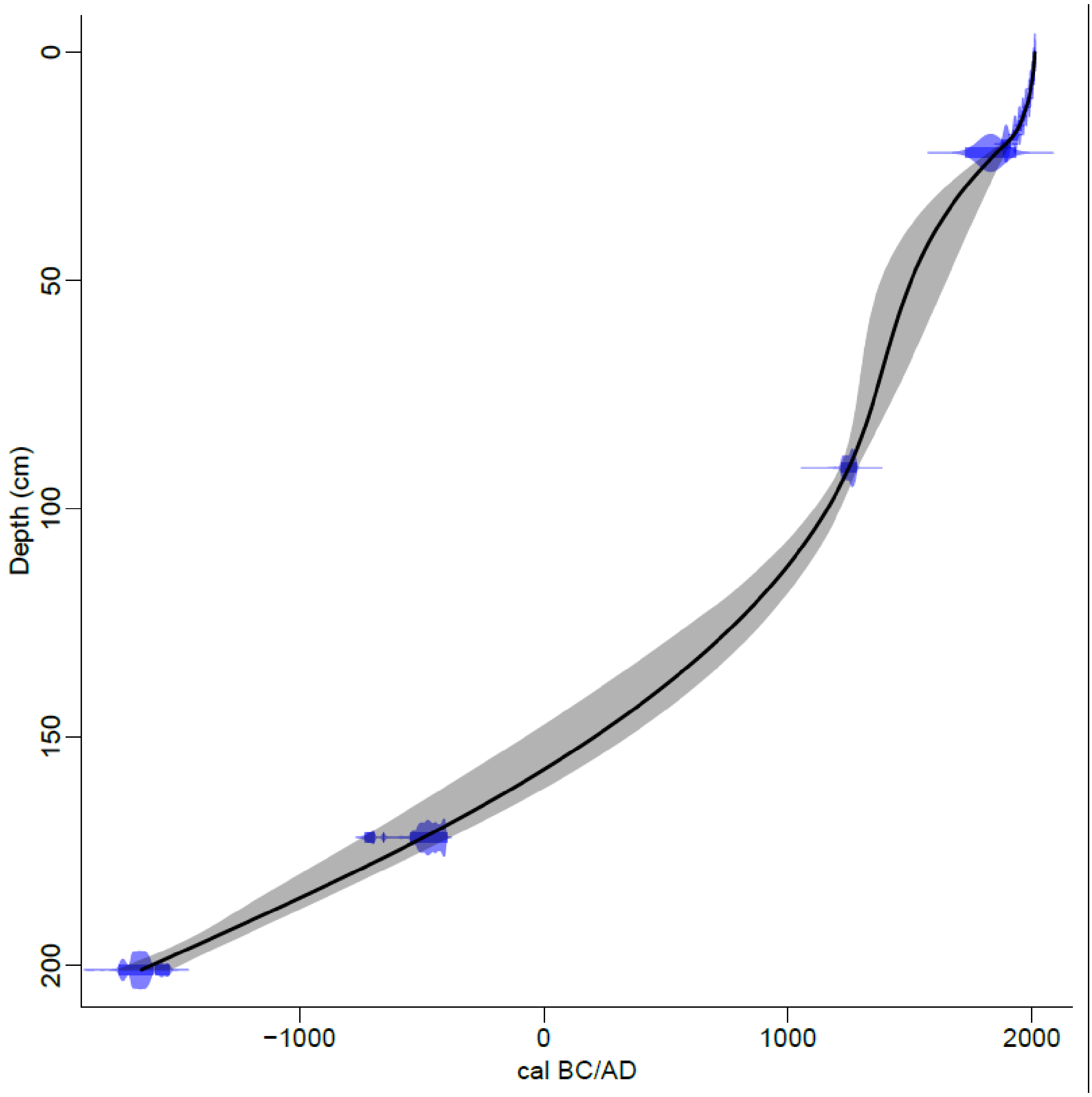


Figure 1: Age-depth model for the SOS peat core using Clam (Blaauw, 2010).

3.2 Geochemistry

Profiles for the major, minor and trace lithogenic elements (Silicon, aluminium, titanium, iron, gallium, rubidium and zirconium), trace metals and metalloids (lead, copper, chromium, zinc, nickel and arsenic), and halogens (chlorine, bromine) are shown in figure 3.

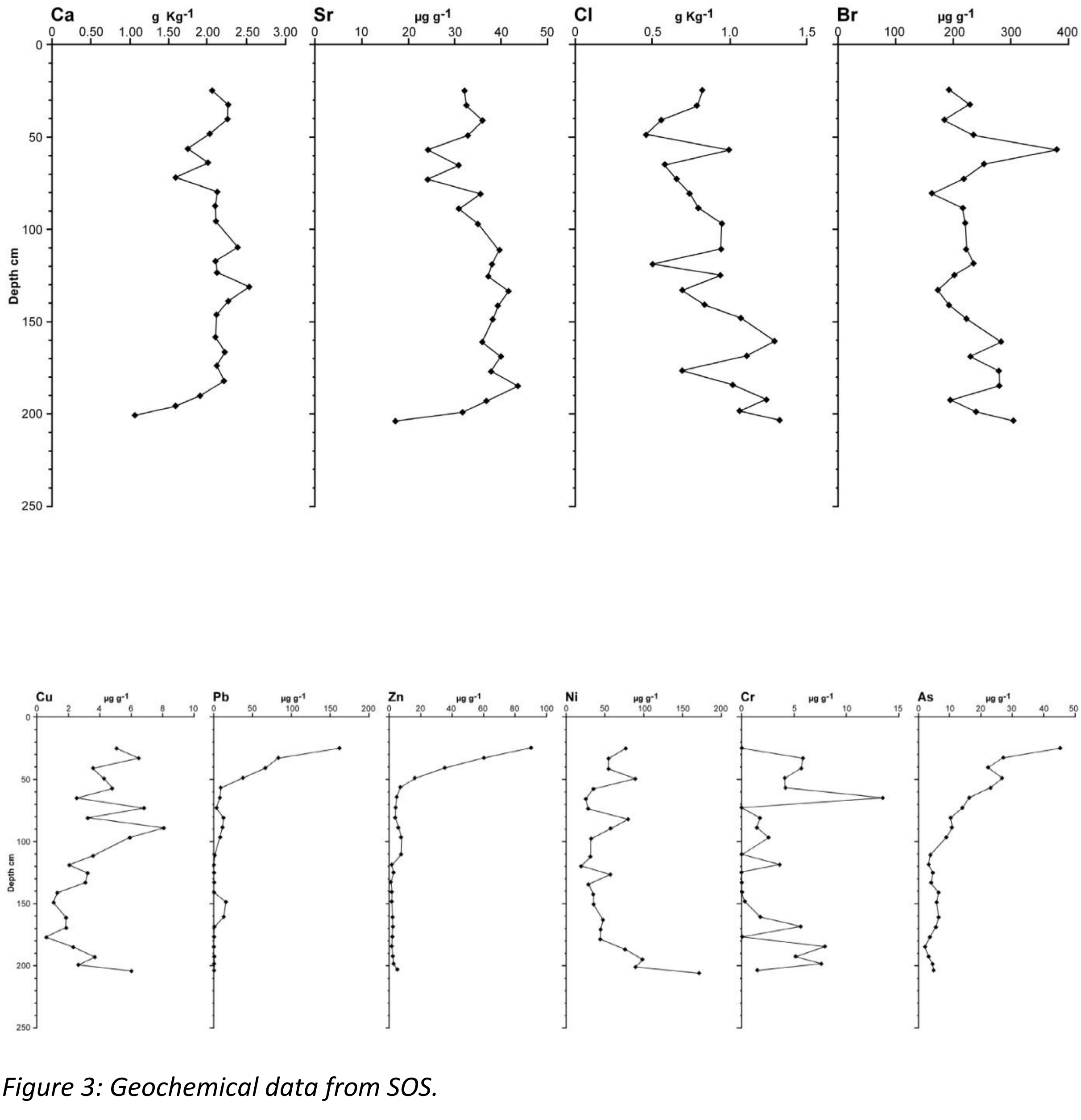


Figure 3: Geochemical data from SOS.

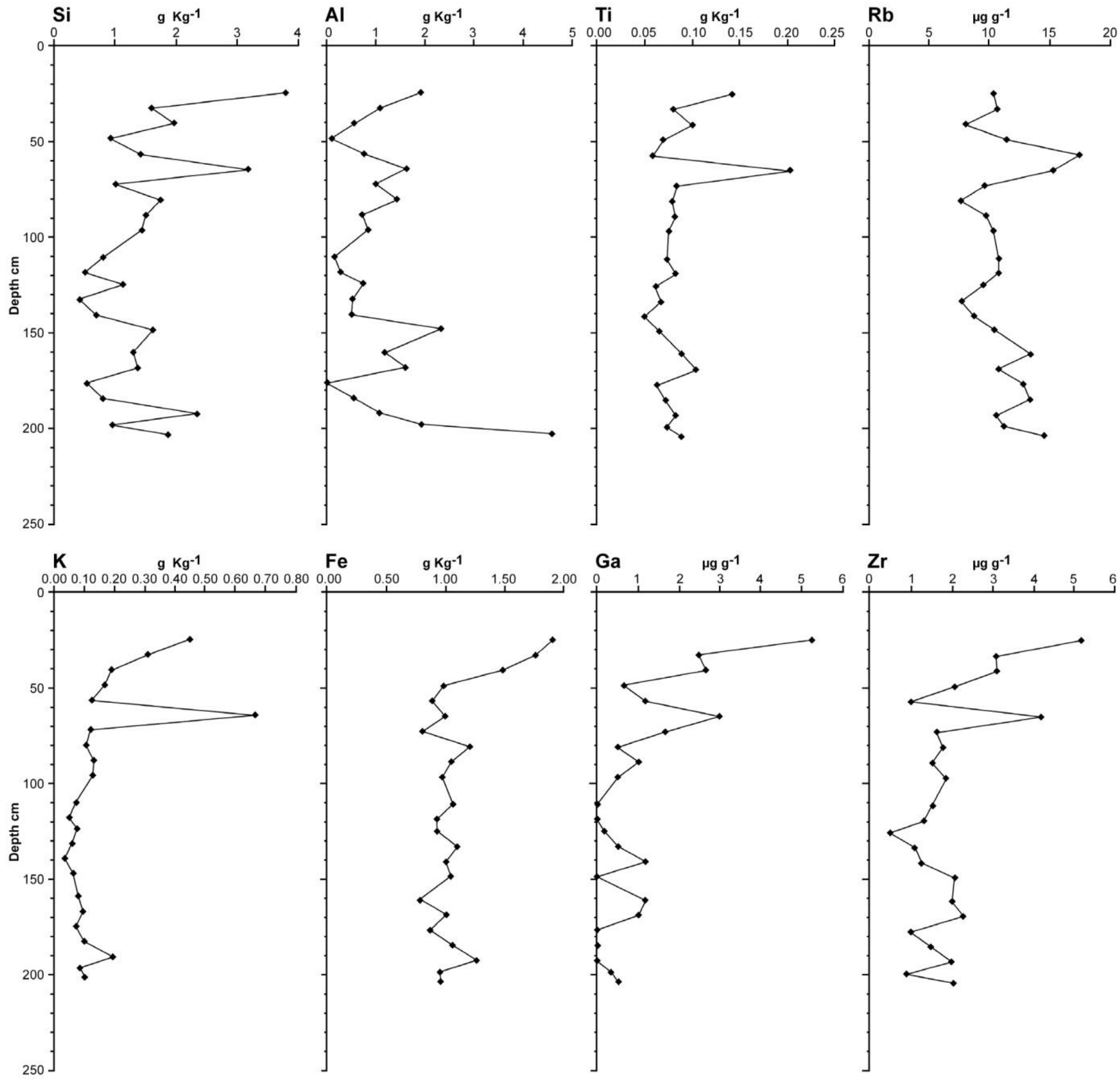


Figure 3 continued: Geochemical data from SOS.

Lead concentrations are very low at the base of the profile and then show elevated concentrations in three phases up core: between 170 cm and 148 cm; from 112.5 to 80 cm and then a sustained rise from 58 cm to the uppermost sample at 24 cm. Arsenic and zinc have similar trends: Arsenic concentrations are relatively low until 112.5 cm and then increase at first gradually and then more rapidly from 42 cm, whereas Zn increases slightly from 120 cm followed by a more sustained rise from 58 cm.

Copper is characterized by low concentrations throughout the profile with no clear pattern. Like copper, nickel has relatively high concentrations at the base of the core. Lower concentrations occur from 186 cm up core, with the occasional peak. Chromium is also similar except for the larger peak at 66 cm.

Calcium and strontium have very similar profiles. They gradually rise from the base of the core and then remain relatively constant except for a reversible dip in concentrations between 80 and 50 cm. Iron is a redox-sensitive element and may be related to changing redox conditions. The halogens (chlorine and bromine) also have similar profiles but no clear pattern. The ocean is the main source for both halogens. They are deposited on to the bog surface by wet precipitation. Once deposited they are susceptible to halogenation reactions (under oxic conditions) control their incorporation into organic matter during peat decomposition. Both processes are climate controlled, in particular by precipitation, thus this component may bear a climatic (i.e. rainfall) signal.

Of the lithogenic elements, only aluminum has significant enrichment at the base of the profile. The concentrations of the other elements (titanium, potassium, rubidium, zirconium, iron, silicon, gallium) are relatively low and fluctuate rather erratically up core. A more noticeable increase in potassium, iron, gallium, zirconium, silicon, and to a lesser extent, aluminum and titanium occurs from approximately 50 cm upwards towards the bog surface. Silicon, rubidium, titanium, potassium, zirconium and, to a lesser extent, gallium, also peak between 56 and 60 cm.

3.3 Microfossils

The updated pollen and NPP diagrams are shown in figures 4A and 4B. The data are presented in the same format as described by Mighall et al. (2012).

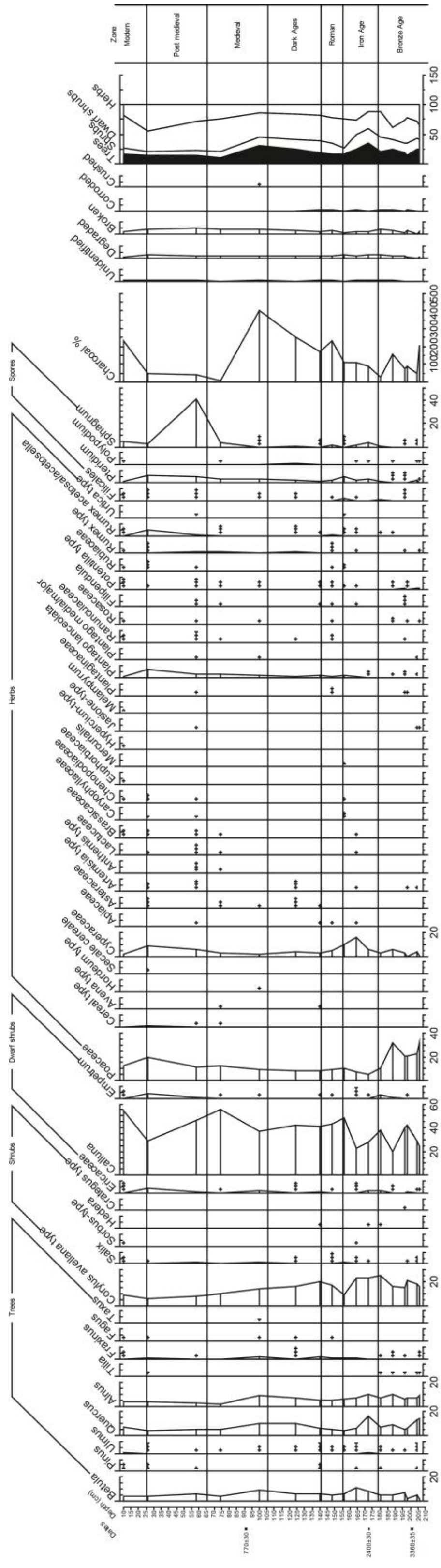
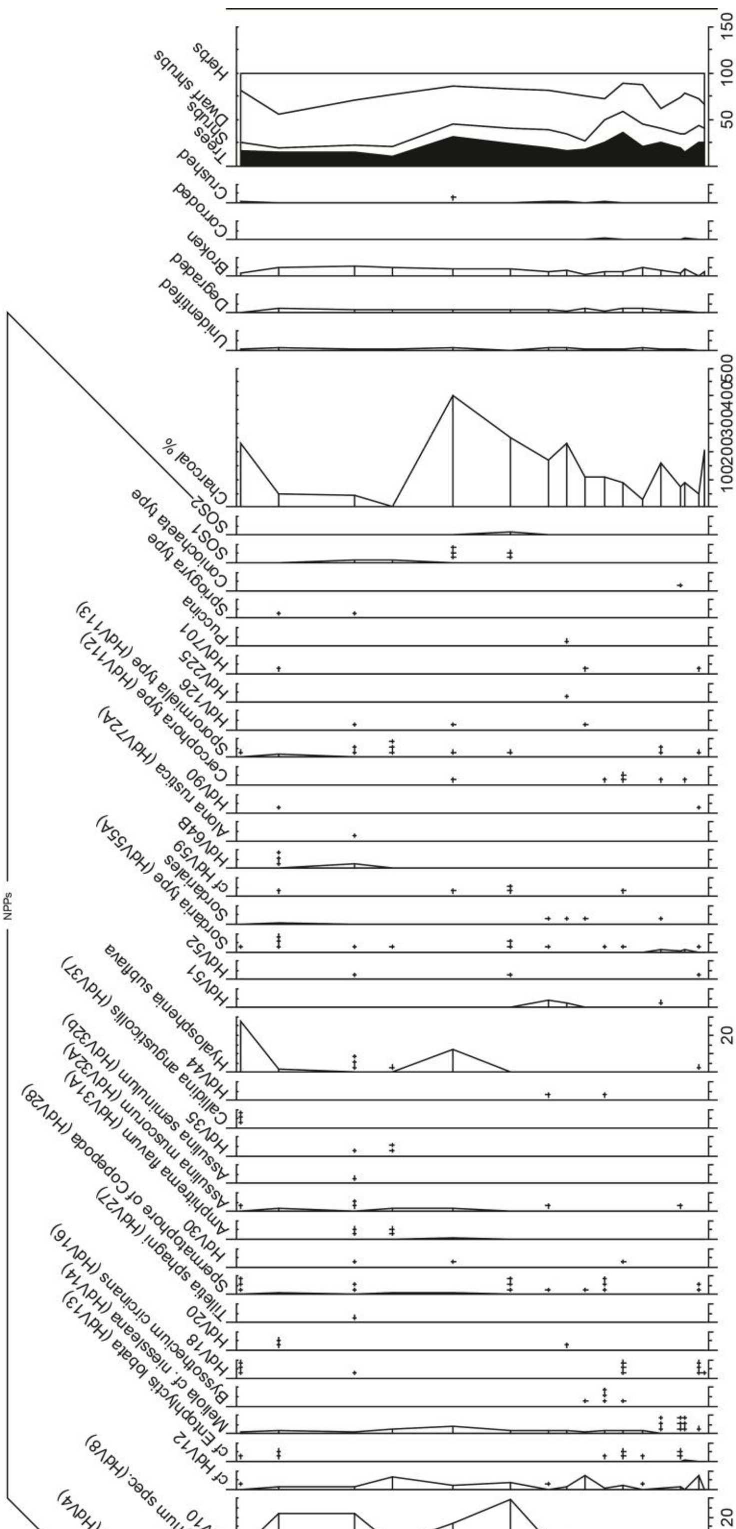


Figure 4A: Pollen data from SOS.



Herbs
Dwarf shrubs
Shrubs
Trees
Crushed
Corroded
Broken
Degraded
Unidentified
Charcoal %
SOS2
SOS-1
Coniochaeta type
Spirogyra type
Puccinia
HdV701
HdV225
HdV126
HdV90
HdV64B
HdV59
Sordariales
HdV52
HdV51
Hyalosphenia subflava
HdV44
HdV35
HdV30
HdV20
HdV18
cf HdV12
NPPs
50
100
150
100200300400500
20

Figure 4B: NPP data from SOS.

4. INTERPRETATION AND DISCUSSION

This section interprets the updated microfossil and geochemical records from the SOS core. Most of the original interpretation of the pollen and geochemical data still remains valid (see Mighall et al., 2012). However, the additional dating, geochemical and microfossil data necessitates a re-assessment of some of the interpretations made in the original report, especially those which have been affected by the improved chronology and resolution of the datasets. These issues are considered in the following sections.

4.1 Bronze Age

One of the most important archaeological sites dated to the Bronze Age in the study area is *Nantyreira Mine* [SN 827874]. The mine is located at around 500m AOD within the upper reaches of the Eira valley (a tributary of the Afon Hore and River Severn) on the lower easternmost slopes of Pen Pumlumon Arwystli. The Early Mines Research Group re-excavated a shallow tip in 1988; recovering two charcoal samples from firesetting activities which were radiocarbon dated to 3390+/-80 yrs (1890-1504 Cal BC) and 3410+/-50 yrs (1880-1610Cal BC) (Timberlake 1990 & 2009).

Previous studies have shown that pollution generated by past mining and/or metallurgical activities can be preserved in a bog and therefore provide evidence for past activities even when the archaeological record is not forthcoming (Mighall et al., 2002a,b, 2009). One of the aims of the new geochemical analysis was to identify possible phases of copper exploitation in the study area. A copper profile for Plynlimon is shown in Figure 3. New recalibrated age estimates of the charcoal dates cited above (using Calib 7.0.1) overlap with the basal peat part of the record (a core depth of 198 cm is estimated to equate to *c*. 1520 Cal BC). The basal two points on the copper profile coincide with this time period. They show a steep decline in copper concentrations from 205 cm to 194 cm. However, concentrations are low and there is insufficient resolution to suggest that the relatively elevated basal concentration is linked to mining.

The resolution of the pollen diagram in the Bronze Age has been improved by counting some additional samples (Fig. 4A). A short-lived phase of forest disturbance, characterised by a slight decrease in *Quercus* and *Corylus avellana* type pollen, occurs at 195 cm, and has a revised estimated age of *c*. 1400 Cal BC. After a period of woodland recovery, another short-lived and small scale disturbance commencing at 188 cm (*c*. 1110 Cal BC) takes place. *Quercus, Alnus* and *Betula* are the most affected tree taxa. Percentages of *Corylus avellana* type pollen increase, suggesting that hazel has taken advantage of a more open woodland canopy. Microscopic charcoal peaks at 188 cm suggesting that fire may have been deliberately used to create woodland clearings although natural fire cannot be ruled out. Herbaceous taxa are sporadically recorded in trace amounts in between the two episodes of woodland clearance. Whilst may of them cease to be recorded after 188 cm, human disturbance of low intensity may have been the cause of these disturbance episodes. Such taxa are indicative of pasture and may be associated with the archaeological sites described in Mighall et al. (2012). Grazing herbivores is also suggested by the presence of coprophilous fungi (HdV-112 and 113). By the end of the Bronze Age, tree and shrub pollen percentages start to increase and the total arboreal pollen percentages return to values similar to those first recorded at the base of the core, suggesting that any human interference on vegetation during the later Bronze Age was of relatively low intensity and non-permanent.

Such clearances are typical of those seen in areas of former early metal mining. Prehistoric mining and/or metallurgical activities had a limited impact on woodlands. Disturbances, such as those described at Borth Bog, Copa Hill and Mount Gabriel, sites with known prehistoric copper mines, are generally characterised by being small-scale, non-permanent and spatially constrained (Mighall and Chambers, 1993, 2000; Mighall et al., 2012). Whether any of the phases of woodland clearance described for the Bronze Age here can be attributed to mining is moot, until further high pollen and geochemical resolution analyses are undertaken.

4.2 Iron Age

Two major phases of woodland clearance were identified in the original pollen record from site SOS. The first, between 172cm and 155 cm, was dated to the late Bronze Age and early Iron Age and described in detail in Mighall et al. (2012). This phase of woodland clearance now is firmly placed in the Iron Age (Fig. 4A) (*c*. 495 cal BC- AD63) and may relate to the probable Iron Age enclosures and hut circles close by. The pollen data supports the contention made by Moore (1968) who suggested that Iron Age cultures were probably responsible for the considerable destruction of forests in the uplands of Wales. This decline also coincides with an intensification of land use, especially grazing as indicated by the renewed presence of pastoral and disturbance indicators in the pollen record.

The intensification of land use is also seen in the geochemical record (Fig. 3). Major, minor and trace lithogenic elements all increase between 170 and 150 cm. Although there patterns do not exactly match, gallium, zirconium, titanium, rubidium, aluminium and silicon all increase. Elevated concentrations of lithogenic elements are often used as proxies for dust input from natural/geogenic sources and they have been interpreted as reflecting land use changes such as deforestation and soil erosion (e.g. Hölzer & Hölzer, 1998; Kempter & Frenzel, 1999; Martínez Cortizas et al., 2005). Therefore dust atmospherically deposited on to the bog surface during this period is interpreted as being a result of land use changes (i.e. deforestation and agriculture).

Given the elevated location of the bog, the record of increased dust deposition represents landscape transformations taking place in the wider region. The timing of the phase of woodland clearance, described above, fits into a pattern recorded elsewhere in central and north Wales. In Snowdonia, for example, extensive phases of woodland clearance have been recorded in pollen diagrams from bogs and lakes in the first millennium BC, between 3000 and 2000 radiocarbon years BP: at 3090 at Crawcwellt Common (Chambers & Lageard, 1993), c. 2700 at Bryn y Castell (Mighall and Chambers, 1995) and at Melynllyn (Walker, 1978), c. 2600 at Llyn Cororion (Watkins *et al*. 2007), c. 2500 at Llyn Padarn (Elner & Happey-Wood 1980), c. 2300 BP at Graeanog Ridge (Chambers, 1998) and more extensive woodland clearance at Nant Ffrancon from 2000 BP (Hibbert & Switsur 1976). At Clogwynygarreg, there is also a gradual decrease in tree pollen percentages which commenced during the Late Neolithic/EBA and continued throughout this period (Grant, 2012). Further south, permanent woodland clearance occurred from 2795±30 years BP (Cal BC 1026–842) at Borth Bog, a coastal raised bog in central-west Wales (Mighall et al., 2009).

4.3 Late Iron Age/ Roman period

A small increase in lead concentrations occurs between 170 cm and 148 cm (Fig. 3). This coincides with the end of the Iron Age and the Roman period. These results suggest that a late prehistoric lead extraction industry may well have developed at this time and that the Romans continued and expanded this industry in the region. The evidence for Roman settlement or occupation within this upland area is slight; the nearest 'permanent' presence here is represented by the Flavian-period (AD140 – 180) marching fort at Penycrocbren on Pen Dylife and the Cae Gaer fort, though at the latter site there is circumstantial evidence of Roman interest in the lead, and unsubstantiated claims of local lead smelting. There are no known immediately local mining remains at Plynlimon (Mighall et al., 2012). The record reconstructed here may well represent a regional pollution signal rather than a local one. It is, however, reasonable to attribute at least part of this phase of pollution to more local sources as there is archaeological evidence for Roman lead mining and smelting at Copa Hill, Borth Bog in central Wales (Mighall et al., 2002a,b, 2009) and further east at Craig y Mwyn in the Berwyn Mountains (Mighall et al., 2007). In the absence of stable lead isotope data, it is not possible to identify specific sources for the lead and the overlap of the signatures of British ores renders it difficult to characterise a specific British source (Le Roux et al., 2004). However, increased lead concentrations from the Late Iron and Roman times are consistent with studies elsewhere in the British Isles e.g. Le Roux et al. (2004) at Lindow Bog in Cheshire. Similarly, Roman peaks have been detected in Flanders Moss and Raeburn Flow in southern and central Scotland respectively (Cloy et al., 2005, 2008; Kuttner et al., 2014). This phase of enrichment also match numerous records for lead contamination published across Europe (De Vleeschouwer et al. 2010, and references therein) and the worldwide Pb production (Settle and Patterson, 1980).

The peak in lead is not replicated in the XRF scanner profile (see Mighall et al., 2012). The XRF scanner lead concentrations do increase from *c*. 165 cm on average and remain higher until about 125 cm and these elevated concentrations might reflect mining and metallurgical activities. Lead concentrations decrease thereafter and there is no definable peak during the Roman period. Peat is not ideal for XRF, because of the high organic and water contents, and this probably accounts for the differences when compared with the EMMA lead data.

4.4 Medieval

A second permanent episode of woodland clearance takes place during early medieval times into the medieval period and is described in detail in Mighall et al. (2012). Originally dated to *c*. AD1015-1385, this phase of woodland clearance can now be revised to *c*. AD 1160-1360. Woodland was cleared to make agricultural land, given the increased presence of indicators of disturbance and pasture, and cereal-type pollen. Some of the upland hafod setlements, for instance in the Afon Hore, at *Bugeilyn* [SN 823930], *Hengwm* [SN 796894] and *Hyddgen* [SN 780909] may have Medieval origins, but actual evidence for occupation within this upland tract is sparse. It seems likely that transhumance agriculture involving the occupation of summer dwellings and grazing of cattle (*lluestai*) and sheep (*haffottai*) was prevalent on these eastern and western flanks of Plynlimon. This is also reflected in the lithogenic elements. Gallium, zirconium, silicon and aluminium all increase during this period. The initial rise in their concentration is staggered, with zirconium increasing first from 126 cm (c AD 770) followed by silicon (118 cm) and then gallium and aluminium (112 cm). The increase in the lithogenic elements suggesting that the phase of woodland disturbance occurred earlier or human activities were generating increased amounts of dust despite the fact that woodland remained unaffected (Hölzer & Hölzer, 1998; Kempter & Frenzel, 1999; Martínez Cortizas et al., 2005). Further pollen analysis could support this suggestion.

4.5 Post medieval

Concentrations of the lithogenic elements continue to increase into the post medieval period, peaking at 64 cm. Although woodland appears to be recovering, albeit very gradually throughout this period, the deposition of the lithogenic elements continues, probably as a result of agricultural activities as arable and pastoral indicators are still recorded in the pollen and NPP diagrams. Other lithogenics, titanium, rubidium and potassium, do not increase during the initial phase of medieval woodland clearance but rubidium does peak between 70 and 50 cm. Potassium and iron are largely unresponsive to the changes in the landscape. After a short-lived decline, the lithogenic elements begin to increase again from approximately 50 cm. Aluminium, titanium, potassium, iron, silicon, zirconium and gallium all show a gradual increase in concentrations. Dust generated by human activities, such as mining and agriculture, are most likely to be responsible, despite the fact that no major landscape transformations occur in the SOS pollen diagram at this time. Apart of titanium, this trend is not clear in the XRF scanner data (Mighall et al., 2012), which suggest that although the XRF scanner produces very high resolution data, it was not able to detect subtle changes in the concentrations of the elements in the Plynlimon core. Better results were achieved at Clogwynygarreg, where increased concentrations of lithogenic elements (namely iron, titanium, silicon) were recorded in the uppermost part of the peat profile and these increases reflect increased dust deposition in an open, cultural landscape (Grant, 2012).

From the mid to late 1500s onwards, (approximately 58 cm at SOS) concentrations of lead, arsenic and zinc all start to increase rapidly. These peaks coincide with the continued development of the lead mining industry from the early medieval period onwards (e.g. Mighall et al., 2004), at pattern that is replicated for lead in the mining district of Glendalough and Glendasan in County Wicklow (Mighall et al., 2013) and elsewhere in Wales including Copa Hill, Borth Bog (Mighall et al., 2002b, 2009) and Clogwynygarreg (Grant, 2012). Moreover, German workers re-organised the English lead mines and new technological improvements such as new furnaces for smelting may have also enhanced lead contamination (Le Roux et al. 2004). Increased concentrations of zinc and arsenic are most likely to be associated with the exploitation of the lead deposits. Arsenic is an element that is often enriched in coals and commonly associated with copper, lead and gold ores (Oremland & Stolz, 2003). The increase in arsenic in the uppermost part of the core is probably the result of mining and coal combustion (Shotyk et al., 1996; Rothwell et al., 2009), although it can also be taken up by plants (Zaccone et al., 2008). Samples in the top 20 cm of the core will be analysed for geochemistry in the near future and the results will provide a proxy record for mining during the modern period.

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