A SPELEOTHEM RECORD OF EARLY BRITISH AND ROMAN MINING AT CHARTERHOUSE, MENDIP, ENGLAND*

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The laser ablation ICP–MS transect of a speleothem from GB Cave, close to Charterhouse, Mendip Hills, UK, records Pb variations over the past 5 ka. The speleothem record correlates well with the known historical record of lead mining in the district, the principal features of which include: the Roman lead mining peak; the Dark Ages cessation; gradual, episodic revival up to the late 16th century peak; the 17th century collapse and subsequent recovery; and the final short-lived burst at the end of the 19th century. This correlation supports the assumption that the pre-Roman lead record also derives from local mining. Thus, this record is the first example of quantifying ancient human mining activity through trace element signature of a speleothem. This record also provides the first solid evidence of significant pre-Roman mining activity in the Charterhouse region, and the first solid dating of that activity. This pre-Roman mining can be divided into three main peaks dated to 1800–1500 BC, 1100–800 BC and 350–0 BC.

KEYWORDS: CAVE, MINING, BRONZE AGE, BRITAIN, LEAD, SPELEOTHEM, LASER ABLATION

INTRODUCTION

The progress and decline of ancient Western civilization was closely attuned to the production of metals, especially silver and lead (Rosman et al. 1997). During the tenure of the Roman Empire, Western European lead production alone amounted to some 80 000–100 000 metric tons per year (Nriagu 1996). Britain was recognized as an important mining region prior to the beginning of the Christian Era, and its production of tin from south-western Britain, and particularly lead from the Mendip Hills, are thought to have been a factor in precipitating the Roman invasion of Britain in AD 43 (Ellis 1992). Nevertheless, the surviving record of the Mendip Roman lead mining industry is sparse, and of its inferred Bronze and Iron age precedents almost non-existent, largely because the landscape is a palimpsest of subsequent mining activity that persisted into the early 20th century. Here, we report a record of mining activity at Charterhouse-on-Mendip that is preserved.

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in a speleothem recovered from an underlying cave system, and which has recorded, but not been overwritten by, successive mining episodes.

The Romano-British mining operation at Charterhouse-on-Mendip, Somerset (51.29°N; 2.71°W, Fig. 1), has been recognized as one of Britain’s earliest and most important industrial archaeological sites (Fradley 2009). The site occupies some 27 ha sitting astride the Blackmoor Valley/Velvet Bottom drainage, which originates on the limestone/mudstone sequence of the Carboniferous Avon Group before flowing on to the purer Black Rock Limestone, where the intermittent stream sinks into one of a number of karst sinkholes locally called ‘swallets’. Today, the site is notable for its ‘gruffy ground’—a mélange of shallow mining pits, linear mining trenches called ‘rakes’ and vegetated mining slag dumps. Archaeological evidence includes earthworks dating from the Mesolithic and Iron Age, a small Roman fort, medieval field structures and smelting flues dating from the early 19th century (Fradley 2009).

The geological context of the Charterhouse lead deposits has been described in detail by Stanton (1985, 1991), from the fortuitous survival of original material in the natural cave accessed from Grebe Swallet Mine. The galena was emplaced as thin veins in Neptunian dykes of Liassic Age, and was especially abundant as redeposited pebbles and concretions in muds and sediments infiltrating the underlying limestone. Preferential dissolution of the limestone over geological timescales then concentrated the lead ore into a surface lag deposit. (Pliny noted that lead was found ‘at the surface of the ground so abundantly that a law was spontaneously passed to limit production’: Bostock and Riley 1855.) These deposits were linear, approximately horizontal and shallow. Presumably, natural erosion by the stream in Blackmoor Valley would have left pebbles of galena exposed, where they must have attracted the attention of the local population. Excavation of Charterhouse Warren Farm Swallet, located 1.5 km south-west of the main Charterhouse mining area, has yielded human remains dating to 2460–1995 BC (Levitan and Smart 1989), demonstrating a human presence in the immediate area since at least the Early Bronze Age: extensive evidence of occupation since Palaeolithic times is known from various Mendip sites, notably Gough’s Cave, Cheddar, some 2.5 km distant (Currant et al. 1989; Jacobi 2004; Jacobi and Higham 2009).

Although all recent authors have accepted that a substantial pre-Roman lead mining industry must have existed at Charterhouse (e.g., Ellis 1992; Todd 1996a,b; Fradley 2009), direct evidence is sparse. A denarius from the reign of Julius Caesar, struck in 48 BC, that was excavated from a Charterhouse mining rake in 1993–5 along with Iron Age pottery sherds is strongly suggestive of first century BC mining, but not conclusive (Todd 1996a).

Ancient lead mining industries produced substantial local, and even regional, pollution. Ore was washed in local streams, which would have introduced soluble lead compounds into the local water table. The smelting took place in open wood-fired hearths (Tylecote 1964) and produced copious emissions of sulphur dioxide and particulate lead (closed smelters with horizontal stone flues for the recovery of volatile lead and sulphur were not introduced until the late 18th century: Gough 1967), which were well understood to contaminate grassland and render it unusable by livestock. On a regional scale, Roman lead smelting between 600 BC and AD 300 in Greece and Spain produced enough air pollution to deposit a record in Greenland ice cores (Rosman et al. 1997). Total lead production from the Mendip orefield has been crudely estimated at approximately 100 000 tons (Green 1958). Ancient lead smelting was also inefficient: Roman slags at Charterhouse have been shown to contain 22 ± 4.6% lead, roughly one third of the original ore content. Slag (which in pre-industrial times was primarily oxidized galena, rather than the high-temperature silicate slags of later industrial origin) was dumped immediately adjacent to the mining operations, whereupon at least some of the galena (PbS)
Figure 1  The site location map, showing GB Cave some 3 km to the west of the main focus of both Roman and 18th–19th century mining. The area of ‘gruffy ground’ around the cave site is shown. The area of intensive mining activity around Blackmoor Valley/Ubley Warren that is enclosed in the doglegged rectangle shows details of Roman and 18th–19th century mining remnants (based on a map from the University of Bristol Speleological Society 2012, which is reproduced in the British Geological Survey website: http://www.bgs.ac.uk/mendips/industrial_archaeology/inukarch.html. The inset map shows the location in South West England.
would have oxidized to anglesite (PbSO₄) or been converted to cerrusite (PbCO₃) under the action of carbon dioxide–rich meteoric water. Both minerals are relatively soluble (0.04 g/l and 0.0011 g/l at 20°C, respectively: Weast and Astle 1982) and can readily enter surface drainage and groundwater. Morgan (1900) has estimated that some 10% of the lead placed in the furnaces was volatilized and lost to the atmosphere, which implies the emission of some 10 000 tons (~1 × 10⁷ kg) of lead, much of which was presumably deposited in the immediate vicinity of the mines.

The Charterhouse area hosts a number of extensive and well-studied cave systems, generally developed in the lower units of the Black Rock Limestone as it dips to the south at 15°–30° (Waltham et al. 1997). GB Cave consists of 1950 m of passages extending to a depth of 135 m, but is better considered part of a single GB Cave/Charterhouse cave system totalling 6800 m and having a vertical range of 228 m (Atkinson 2012). GB Cave has long been renowned for its investiture of speleothems, many of which appear to have low detrital content. Speleothems retain the trace element signatures of their formative drip-waters (e.g., Goede and Vogel 1991; Fairchild et al. 2001) and have been previously studied in a speleothem from GB Cave (Roberts et al. 1999). It is therefore reasonable to presume that GB Cave speleothems, lying only a few tens of metres below a landscape heavily contaminated by the lead smelting industry, should retain a record of that industry in their trace element profiles.

MATERIALS AND METHODS

The speleothem used in this study was a stalagmite that had been previously collected from ‘The Bridge’ of GB Cave, Mendip (51.3027°N; 2.7531°W, 258 m a.s.l.) and sectioned and dated by other studies (Dennis et al. 2001). A subsection of the stalagmite (Fig. 2) was used in this study. Elemental analyses were performed on a GBC Optimass 8000 time-of-flight mass spectrometer linked to a New Wave UP-213 ultraviolet laser ablation system. Data were collected during ablation of 30 μm spots spaced at 150 μm intervals. Data were calibrated using standard glasses SRM-614 and NIST-612, with calcium used as the internal standard. Uranium–thorium dating was done by thermal ionization mass spectrometry (TIMS). Ages were calculated using half-lives from Cheng et al. (2000). These very clean samples (as indicated by the high ²³⁰Th/²³²Th activity ratios; Table 1) required no correction for detrital contamination.

The age model was constructed using the date of collection (1980) and the six TIMS-dated horizons (dated in 1997) by fitting a polynomial curve to each of three overlapping sections following the curvature of the transect (upper, middle, base). Each dated sample was cut about 3 mm thick and parallel with the growth lines. The exponential nature of the decay equations means that the resultant date represents a point slightly to the older side of the mid-point, ~58% of the sample thickness, or in this case ~1.74 mm from the top of the cut piece. The error on the time scale includes the analytical error of the dates (ranging from ±4 to ±34 years) and the stratigraphic error (error in cutting and in tracing growth lines from the dated position to the transect position). The stratigraphic error combined with error in curve fitting was estimated at about 1 mm. The actual age error represented by this 1 mm varies with growth rate, being greater for periods of slower growth.

The 551 points measured along the transect were screened for potential bias caused by: (i) sampling fine detrital particles rather than calcite crystals (all points with >1000 ppm Si were removed); and (ii) sampling fluid inclusions rather than crystals (all points with Ca values lower than 2.5 standard deviations from the mean were removed). This resulted in the exclusion of 24 points (but, in the end, this exclusion made no significant difference to the final graph).
RESULTS AND DISCUSSION

The results from the U–Th dating are shown in Table 1 and the Pb concentration is plotted against age in Figure 3 (raw data and five-point running mean). The error on the age scale is shown as a ribbon around the five-point running mean, the width varying over time. The lead

Table 1  The results of TIMS U–Th dating: all ratios are activity ratios and errors are 2σ

<table>
<thead>
<tr>
<th>Sample</th>
<th>Age</th>
<th>U (ppm)</th>
<th>$^{230}$Th/$^{234}$U</th>
<th>$^{234}$U/$^{238}$U</th>
<th>$^{230}$Th/$^{232}$Th</th>
<th>$^{234}$U/$^{238}$U initial</th>
</tr>
</thead>
<tbody>
<tr>
<td>GB40 Top</td>
<td>225 ± 4</td>
<td>19.8</td>
<td>0.00206 ± 0.00003</td>
<td>3.3212 ± 0.0092</td>
<td>113</td>
<td>3.323</td>
</tr>
<tr>
<td>GB40 06</td>
<td>1995 ± 8</td>
<td>14.0</td>
<td>0.01814 ± 0.00007</td>
<td>3.2974 ± 0.0128</td>
<td>2695</td>
<td>3.310</td>
</tr>
<tr>
<td>GB40 12</td>
<td>2494 ± 6</td>
<td>15.2</td>
<td>0.02264 ± 0.00005</td>
<td>3.2681 ± 0.0053</td>
<td>2187</td>
<td>3.284</td>
</tr>
<tr>
<td>GB40 18</td>
<td>3125 ± 5</td>
<td>12.5</td>
<td>0.02830 ± 0.00004</td>
<td>3.2897 ± 0.0059</td>
<td>3563</td>
<td>3.310</td>
</tr>
<tr>
<td>GB40 25</td>
<td>4183 ± 15</td>
<td>11.6</td>
<td>0.03774 ± 0.00013</td>
<td>3.2427 ± 0.0115</td>
<td>2516</td>
<td>3.269</td>
</tr>
<tr>
<td>GB40 36</td>
<td>5136 ± 35</td>
<td>14.6</td>
<td>0.04617 ± 0.00030</td>
<td>3.2376 ± 0.0075</td>
<td>5357</td>
<td>3.270</td>
</tr>
</tbody>
</table>

A speleothem record of early British and Roman mining

Figure 2  The positions of dates and of the LA–ICP–MS transect. The dates were done as part of a previous study (Dennis et al. 2001), which also consumed the majority of the sample, thereby limiting the material available for this transect.
Figure 3 A plot of Pb (ppm) versus dates (the raw data are shown by the fine dotted line, and the five-point running mean by the solid line). The error on the age scale is represented by the thick pale ribbon around the five-point running mean, the thickness varying over time, being least between about 1500 BC and about AD 300. TIMS dates are shown by the black squares, the 2σ error being smaller than the symbols.
record is non-random, has a modal value in the 10–20 ppm range and is skewed by several obvious peaks.

There has been some discussion in the recent literature on trace elements in speleothems about the importance of colloidal transportation of some elements (e.g., Fairchild and Baker 2012). If this were true of the Pb in the GB sample, then the record might be significantly biased by hydrological events. Fairchild et al. (2001) and Hartland et al. (2012) suggest that transportation by organic colloids should be indicated by covariation of elements that are strongly bound to colloids (such as Pb, Zn, Y, Cu, Ni and Co) in contrast to those not transported colloidal, such as Sr and Ba. If colloidal transportation was a significant factor in the elemental distribution of the GB sample, then we would expect some of these (non-Pb) elements whose record is not conflated with mining activity to covary. This is not supported by the data: for example, $R^2_{Zn,Y} = 0.12$, $R^2_{Zn,Cu} = 0.01$, $R^2_{Zn,Ni} = 0.24$, $R^2_{Zn,Co} = 0.18$, $R^2_{Y,Cu} = -0.06$, $R^2_{Y,Ni} = 0.09$, $R^2_{Cu,Ni} = -0.03$, $R^2_{Ni,Cu} = -0.07$. Equally, there is no evidence of covariance with the non-colloidal-transported elements: for example, $R^2_{Cu,Sr} = 0.07$, $R^2_{Cu,Ba} = -0.15$, $R^2_{Zn,Ba} = -0.02$. Further, the absence of correlation of the Pb record with any of the recognized colloidal-transport markers (e.g., $R^2_{Pb,Cu} = 0.2$, $R^2_{Pb,Y} = 0.06$), nor with any other of 54 elements co-analysed (e.g., $R^2_{Pb,Al} = 0.15$, $R^2_{Pb,Th} = 0.04$, $R^2_{Pb,Fe} = -0.04$, $R^2_{Pb,Zn} = 0.1$), supports our conclusion that colloidal transportation is unlikely to be a significant factor in the Pb record from GB.

For this study, the spatial scale of sampling is not significantly different from the annual growth rate. Thus the possibility that aliasing may have biased the record must be addressed. If aliasing were important, then all elements that show a distinct seasonal variation (such as Sr, Cu, Pb, Y and Zn: Borsato et al. 2007) would be magnified/minimized in the same manner and would be expected to correlate with each other and with Pb. That they do not in our record implies the absence of aliasing bias.

The galena ore is not very soluble in rainwater (Stanton 1991), so natural leaching from undisturbed ore-bodies is presumed to be minimal and at a relatively constant rate. We have used a sample of Last Interglacial (MIS 5e, ~125 ka) flowstone from Lamb Leer (Wells and Mendip Museum specimen #6/1989/30), a cave ~6 km east of Charterhouse that lies below a lead mining orefield, as a ‘control’ for the pre-anthropogenic lead record. LA–ICP–MS analysis of a transect spanning some 5000 years of this sample yielded a mean lead content of 8 ± 16 ppm (the variation being randomly distributed). Background levels of lead in the GB stalagmite sample are in the range of ~10 ppm, quite comparable with the Lamb Leer ‘control’ levels.

Peak events in the GB Pb record reach ~100–120 ppm. The excess lead is potentially from three main sources: atmospheric fallout from smelting, groundwater leaching of slags and ore, and disruptions of the soils/sediments by digging. Thus, variations in the stalagmite probably reflect, in addition to the natural background levels, changes in the relative contributions of these sources, some more regional and some more local in scale, as well as a short lag time between stimulus and response related to mixing of waters in the epikarstic zone (Smart and Friederich 1987). The high correlation between the lead and uranium records ($R^2$ for raw data Pb versus U = 0.51, running means Pb versus U = 0.60), which is not seen in the silica ($R^2$: 0.04), aluminium ($R^2$: 0.11), strontium ($R^2$: 0.20) or barium records ($R^2$: 0.16), is strongly supportive of the hypothesis that we are seeing a record of mining and smelting, rather than climatic events that might have changed the leaching and delivery pattern of trace elements into the cave. We first tested the hypothesis that Pb levels in the speleothem mirror human activity by comparing Pb levels with the known history of mining activity in the region during the Roman and post-Roman times. Then we looked at the prehistoric record.
Roman era

Roman interest in British metalliferous resources, particularly lead, silver and tin, pre-dated the invasion of AD 43. Cornish tin had been traded to the Mediterranean powers as early as the fourth century BC (Welsh 1963), and these resources would have been familiar to Julius Caesar when he began his British campaigns in 55 BC. Following the successful Claudian invasion, the Romans established themselves at Charterhouse very quickly. Comments by Whittick (1982) notwithstanding, detailed research has confirmed that Roman production and export of lead pigs was under way no later than AD 49 (Todd 1996b), just 6 years after the invasion—indeed, some authors have speculated that control of the Charterhouse mines may have been a major motivation and primary target for the invasion (e.g., Dobson 1931; Ellis 1992). If this were the case, Roman production probably commenced within a year or two of the invasion.

The GB Cave record shows the first, modest, ‘Roman’ peak at c. AD 50–150 (± ~50 years), which corresponds well with Todd’s (1996b) analysis of recovered lead pigs that are most frequent in the latter decades of the first century AD. A lead minimum in the last part of the second century AD suggests that mining on Mendip may have waxed and waned with political stability (Whittick 1982). Thereafter, the lead record begins a steady climb, peaking at c. AD 400. The end of the Roman era is marked by a precipitous collapse in lead levels to a minimum around AD 600 correlating with the onset of the invasions of, and possible replacement of, the Britons in the region by Anglo-Saxons (Stenton 1973, 314–15) and the start of the Dark Ages.

The post-Roman era (AD 400–1900)

The correlation between the speleothem lead record and mining activity continues in the post-Roman period, c. AD 400–1900, for which there is a documented history (Gough 1967). There is a rapid decline in lead content from Roman era levels to background levels in the seventh to ninth centuries—the ‘Dark Ages’—correlative with no recorded mining activities. A minor but short-lived recovery between the end of the ninth century and the mid-10th century might be correlated with the increasing civil stability associated with the beginnings of the proto-English state under King Egbert (reigned AD 802–39), Alfred the Great (reigned AD 871–99), and the rise of Athelstan, first king of all England (AD 925–39). The decline in Pb levels to background levels over the course of the 10th century correlates with increasing Viking invasions (Heritage History 2012), culminating in the Norman conquest in AD 1066. Subsequent to this, increasing civil stability and industrial activity in Norman times is mirrored by a steady increase in the speleothem lead record. The construction of nearby Wells cathedral, begun in AD 1175, and dedicated in AD 1239, testifies to the general wealth of the Church lands, of which the most important were almost certainly the Mendip mines (Gough 1967), and also would have created a significant local demand for lead roofing.

Mining activity generally flourished over the next few centuries, with rises and dips that continue to reflect civil stability. The stable period of the 13th century (a time of population expansion and the expansion of the first British universities) is marked by a Pb peak, followed by the 14th century dip during a time of war and plague (the Hundred Years’ War with France and the Black Death: Encyclopedia Britannica 2012). The next dip, showing in our record at c. AD 1500, correlates with documentary evidence that the mines were doing poorly in Tudor times (Gough 1967). The late 16th century peak marks the prosperity of the Elizabethan period, the height of the ‘English Renaissance’ (Hadfield 2001), a time of rapid growth of population.
and of towns. The subsequent sharp decline in the lead record around AD 1600–1700 broadly correlates with the internal conflict that culminated in the English Civil War (AD 1642–9).

The subsequent recovery of the Mendip mining industry in the 18th century, mirrored by the GB record, is well documented (Gough 1967). This was probably driven by new metallurgical technologies (Burt 1991). Recent scholarship (Vergani 1979; Hollister 1985) has shown that gunpowder was in use in European mines at least as early as 1574. The introduction of gunpowder to British mining was much later, commonly cited as dating to c.1662 (Barnatt et al. 1997), but which is now recognized to have occurred by 1638 (Earl 1978). It is possible that the GB Cave lead record, which begins a steep increase in the late 17th century, might reflect the reinvigoration of the industry by the introduction of gunpowder into the British mining industry, which would have made deeper excavations into the Charterhouse limestone more economically attractive.

Mendip lead mining saw a rapid decline and had ceased by the middle decades of the 18th century (Gough 1967). The final revival of Mendip lead mining, a rather short-lived burst from 1858 to 1908, was based on reworking slag, with evidence of much mobilization of sediments and some extreme pollution (Macklin 1985). These short-term peaks and troughs are masked in the smoothed GB data, but the raw data signal parallels them, with a steep post-1750 decline, and a steep rise at c.1800 peaking in c.1880. This is followed by a rapid drop at the very top of our transect just after AD 1900.

The pre-Roman era

Having shown that the speleothem lead signal faithfully follows the known historical record of mining activity, we then examined it for the time period with very little documentary evidence. It is generally acknowledged (e.g., Ellis 1992; Todd 1996a,b; Fradley 2009) that mining must have already have been established in the Mendip area to attract the attention of the Roman invaders. However, the pre-Roman record is quantitatively and chronologically unknown.

A notable feature of the GB Cave speleothem record is a marked spike in lead levels, peaking at c.1600 BC, corresponding to the latest part of the Early Bronze Age (Pearson 2005). This peak is the second highest in the ~5000 year record, and may well represent the earliest lead mining and smelting in the district. It is of note that the Bronze Age copper mine at Great Orme in Wales has yielded radiocarbon dates of 1465–1885 cal BC (2σ; Lewis 1996), the copper mines at Cwmystwyth, Wales, have produced a radiocarbon age of 2000–1900 BC (O’Brien 1996) and the copper mines at Ross Island, County Kerry, Ireland date from 2400 BC to 2000 BC (O’Brien 1996), so there is no question that metallurgical technology was available in the British Isles at that time. The possibility that the earliest mining at Charterhouse was targeted on copper, rather than lead, is contraindicated by the lack of a Cu/Pb correlated signal in the speleothem. Higher-than-background values for Pb in the interval 3000 BC to 2000 BC may reflect early Bronze Age lead mining, or may result from Bronze Age forest clearance and its associated disturbance and destruction of soil profiles and probable disturbance of the galena surface lag deposits (Todd 1996a). Around 1500 BC, lead levels drop precipitously to background levels, where they remain until c.1100 BC, after which they increase to a second major peak around 1050 BC—an interval corresponding to the Wilburton Phase when leading of bronzes was common (e.g., Rohl and Needham 1998)—before declining to background around 700 BC, perhaps correlating with the transition into the Iron Age. More sporadic activity is indicated between c.600 BC and AD 0. Overall, the record suggests that there were three distinct episodes of pre-Roman mining in the Charterhouse district: (I) c.1800 BC to 1500 BC; (II) c.1100 BC to 800 BC; and (III) c.350 BC to AD 0.
A complicating factor is that these peaks correlate with broad-scale changes in climate. Charman et al. (2006) produced a regional composite water table record for northern Britain over the past 4500 years, arguing, from the correlation with periods of high lake level in mid-Europe (Magny 2004), and the correlation with the records of ice-rafted debris in the North Atlantic (Bond et al. 2001), that major changes in terrestrial water table balance are broadly synchronous throughout north-west Europe. These climate oscillations affected human activity; for example, the cooler, wetter period around 800–550 BC correlates with a sharp decline and collapse of the bronze industry in Britain (Brown 2008), glacier advance in Europe, abandonment of highland settlements and lowering of the tree line (Lamb 1964, 1982). Figure 4 shows the GB speleothem Pb record for the period from c.2200 BC to 0 BC (which brackets the three pre-Roman mining episodes) against these three indices of regional climate change. Notable is the distinct correlation of high Pb with reduced ice-rafted debris, a low water table and low lake levels. We conjecture that mining activity varied as population density responded to changing climatic conditions.

The pre-Roman lead record in the GB Cave speleothem proved to be more complex than was originally anticipated and leads to questions about the relative amplitude of the signal at different times. The evidence found so far points to Roman mining focused on centres such as Charterhouse and Ubley Warren, close to the local concentrations of galena (Todd 1996a), but not in the immediate environs of GB Cave. Thus is it likely that, during the time of Roman mining and smelting, the lead reached the cave by atmospheric deposition only, and it is likely that this ‘Roman’ record is somewhat subdued because the cave was upwind of the smelters at Charterhouse. While mining may not have occurred above GB Cave in Roman times, the abundance of ‘gruffy ground’ indicates that mining directly above the cave certainly did occur at some time and was probably not confined to a single era. Local mining obviously contributes a much more immediate and substantial Pb load to the speleothem. We conjecture that the pre-Roman peaks are

Figure 4  The Pb record for the period of pre-Roman mining activity (thick line) correlated with regional climatic indicators arranged to show drier, warmer conditions at the top and wetter, colder conditions at the bottom. The record of ice-rafted debris from the North Atlantic is from Bond et al. (2001) (thin line, with reversed scale), the composite record of regional water table variations from Charman et al. (2006) (dashed line, with reversed scale), and the periods of high lake level in mid-Europe from Magny (2004) (shaded rectangles).
likely to represent such local mining and are thus magnified in importance in the GB record relative to more distant activities.

CONCLUSION

The results of this laser ablation ICP–MS transect of a speleothem from GB Cave, close to Charterhouse, Mendip Hills, UK, show Pb variations over the past 5 ka. Roman and post-Roman lead mining activities are well documented for this region. The speleothem record correlates well with the known historical record of lead mining in the district, the principal features of which include: the Roman lead mining peak; the Dark Ages cessation; gradual, episodic revival up to the late 16th century peak; the 17th century collapse and subsequent recovery; and the final short-lived burst at the end of the 19th century. This correlation supports the assumption that the pre-Roman lead record also derives from local mining. This record is the first example of quantifying human mining activity through trace element signature of a speleothem. The most important results to emerge from this research are: (i) the correlation of the GB speleothem Pb record with known historical mining activity in the area; (ii) the evidence of significant pre-Roman mining activity in the Charterhouse region; and (iii) the dating of this activity to three main peaks at 1800–1500 BC, 1100–800 BC and 350–0 BC. This record thus provides the first solid evidence of significant pre-Roman mining activity in the Charterhouse region, and the first solid dating of that activity.

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