Where did all the Prehistoric Copper go?

Linking the Great Orme ores to Bronze Age metalwork.

My first visit to the Great Orme mines thirty-five years ago was shortly before the great prehistoric discoveries came to light. I had recently graduated with a degree in mining geology from the Royal School of Mines and within a few years the revelations on British and Irish prehistoric mining came thick and fast. I attended the groundbreaking Plas Tan-y-Bwlch conference in 1989 where I listened with amazement as the pioneers in the field revealed their spectacular discoveries, with the most stunning being from the Great Orme. Over the years I have written a few books and articles on mainly eighteenth and nineteenth century Welsh and Irish mining history. Now, after a long career with Pilkington as their chief geologist, I’m using my specialist knowledge to try and solve one of the outstanding enigmas of the Great Orme copper mine. Where did all the prehistoric copper go? This topic is now the basis of my PhD research at the University of Liverpool, Archaeology Department and the following short article summarizes the work done so far. I have tried to keep the scientific parts as accessible as possible and would refer specialists to forthcoming academic papers which also contain a fuller bibliography.

The famous Welsh antiquary Edward Lhuyd recorded a remarkable discovery made in 1686 in a field at Gloddaeth two miles from the Great Orme:

“...there were found...several brass instruments of the shape of axes, but whether they were British or Roman or what use they were designed for, I must leave to be determined by others. There were about fifty of them placed under a great stone placed heads and points, whereof some are yet preserved...They have been found in several other parts of Wales " This was one the largest hoards of Middle Bronze Age bronze axes or palstaves discovered in Wales and was long before the names of prehistoric periods were coined and the depth of prehistoric time was appreciated.

Could the Great Orme mine be the source of the copper in the Gloddaeth palstaves but more importantly the source of some of the metalwork found across the region, across Britain, and Ireland and perhaps even in parts of the continent? To properly answer this deceptively simple question requires the mobilization and integration of wide range of scientific, archaeological, geological, mineralogical and metallurgical concepts, ideas, samples and data.

Identifying the location of the copper sources during the 1,500 years or so of the British Copper and Bronze Ages can potentially throw new light on local, regional and European exchange networks, reveal important centres of activity and how they changed with time. Indeed there is a growing realization of the significant extent of social interactions and movement across Britain and mainland Europe during the Bronze Age.

What do we know about copper sources in the British and Irish Bronze Age? Current dating evidence from about ninety
radiocarbon dates suggests that the Ross Island mine in S W Ireland was the main source of the earliest Bronze Age copper (2400–1800 BC) followed within a few centuries by smaller mines in North and Mid Wales plus some in west central England (Fig. 2). However, by around 1600 BC all the currently known British mines had probably closed except the Great Orme mine (1884 to 933 BC), which became the only known British copper mine to be working by the Middle Bronze Age. The probable copper metal output from the Great Orme mine exceeded all the other known mines although the current estimates need reviewing.

Previous detailed research on the Great Orme mine has focused on the archaeology of the surface opencast excavations (Dutton et al 1994), establishing criteria for identifying ancient mining underground (Lewis 1996), a detailed analysis of the faunal remains and their implications (James 2011) and a broad review of the character and context of the site (Wager 2001). Other important work has been on the Pentrawyn smelting site, discovered by Dave Chapman in 1987 and also work on the washing sites (Jones 1994; Jones 1996).

To link Great Orme ore to metal, two independent techniques are being used, namely establishing a chemical ‘signature’ using the amount or absence of certain trace elements and a lead isotopic ‘signature’ using the amounts of different lead isotopes. Using these two different ‘signatures’ allows Great Orme metal to be more clearly distinguished from other possible mines. There are many potential complications to this type of ‘signature’ work with ore and metal. The chemical signature can be affected by variability of natural ores and whether, during smelting, the ore trace elements have a natural tendency to transfer into the copper metal or prefer the slag and hence are ‘lost’. The ‘losses’ into the
slag can be affected by variable smelting conditions (oxidizing/reducing) and another factor is the loss of volatile elements like arsenic. 'Foreign' trace elements or lead isotopes can be introduced by the addition of smelting fluxes, alloying metals (like tin and lead) and also from metal recycling. Let’s consider the chemical side of things. Peter Northover (1980) divided all Bronze Age metal artefacts into groups on the basis of their content of arsenic, antimony, silver and nickel during the Early, Middle and Late Bronze Age. He noted a radical change in metal compositions in the Middle Bronze Age to those containing mainly arsenic and nickel across most of Britain. He speculated, on the basis of distribution of objects, that the source was somewhere in North Wales. As this period was when the Great Orme was very active, why not attribute the source to the Great Orme mine? The reason comes down to influential mineralogical studies (without chemical analyses) about twenty years ago (Ixeer et al 1998) which came to the conclusion that the metal produced from the Great Orme ores would be trace element poor and so, by implication, could not produce the dominant arsenic-nickel metal of the Middle Bronze Age. (Fig:3) Hence, the consequence of that conclusion was that the Great Orme mine was not as important in the Bronze Age as the size of the workings would suggest.

Fig. 3: British Bronze Age metalwork. Graph of nickel versus arsenic content.

If only low impurities in Great Orme ores they would lie in this shaded area

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These studies have been quoted in numerous papers and other scholars have indirectly implied disagreement but without suggesting any resolution to the conflicting scientific evidence. The current research has aimed to re-examine the whole topic by adopting new methods and integrating knowledge of ore mineralogy, geochemistry and pyrotechnology.

A variety of analytical methods are being used to ensure the final results are robust. Some analyses have been done in the Archaeology Department of the University of Liverpool (AAS and SEM-EDS) while others were done at laboratories in at the University of Cardiff (LA-ICP-MS), University of Leicester (XRD-WD) and at NIGL Keyworth (MC-ICP-MS)) with specialist advanced technology equipment. The materials being analyzed are the ores, the bronze fragments excavated in the mine and the copper prills found at the Pentrwyn smelting site. Thousands of Bronze Age metalwork samples have been analyzed over past decades and are available in databases.

The first type of material sampled and analyzed are ores. One of the reasons that Great Orme copper mine was probably so extensively worked was that it was one of the largest near surface deposits in Britain of easy to smelt oxide ore (malachite and other oxide minerals) rather than much harder to smelt sulphide ore (e.g. chalcopyrite) which would require multiple stages to remove sulphur and iron. The original chalcopyrite veins have been extensively converted by oxidization (supergene weathering) to an imitate mixture of goethite (hydrated iron oxide) and malachite (a hydrated copper carbonate). In addition, the zone each side of the vein was often soft and friable dolomite allowing the use of simple bone tools. Both these factors may have made the deposit much more attractive (easier to mine) than other British mines in much harder silica rich rocks and could be one of the reasons the other mines closed. In-situ studies throughout the mine have shown that the malachite-goethite ore was the main type worked. While some small amounts of malachite-only ore were observed it was only a minor ore type. Analyses have revealed that the trace elements were often concentrated more in the goethite than in the malachite and so sampling the malachite alone could give a misleading picture of impurity levels. Both the malachite and goethite would have been smelted together.

The second type of material analyzed were copper prills from the nearby smelting site at Pentrwyn. Remains are fragmentary and it appears to have been a small site. A few hundred grams of copper slags and copper prills were recovered from excavations in 1998 and 2011 carried out by Dave Chapman, George Smith and others. Dating of charcoal samples from the 2011 dig were all Late Bronze Age around 900 BC (matching the probable date of Bronze Age metal artefacts found in nearby Pigeon’s Cave) unlike the much earlier single sample from the 1998 dig. The copper slags and prills examined have revealed a lot about the Bronze Age smelting technology being used at the site (see Williams 2014). I think we still lack the major smelting site or sites that probably existed to smelt Great Orme ores. Analyses of the copper prills help us to see whether the trace elements in the ores transfer into the copper metal after smelting.

The third type of material being analyzed are the small pieces of bronze that have been found in the mine, firstly one found in 1831 when miners broke into old workings which could be the point of a bronze pick. Secondly, numerous small fragments discovered during underground excavations in the 1990s and whose origin is less clear but could be from broken picks as seen in Bronze Age mines in Austria. It is reasonable to suppose that this metal was made using ores from the mine and are useful to compare with the ore analyses.
So what are the preliminary results from the research showing? Firstly, let’s look at the chemistry. We can consider a variety of elements but here we shall just look at nickel and arsenic and in Figure 4 you can see a plot of British Bronze Age objects (grey dots). If conclusions from past studies (Iker et al 1998) were correct (i.e. that Great Orme only produces low impurity metal taken as <0.1%) then we would only expect the analytical results from the ores to lie in the small blue shaded square and consequently only match a very small number of artefacts. So what did the results from our ore analyses show (assuming no loss of trace elements and normalizing for copper)? These results (Fig. 4, red square symbols) strongly suggest the metal produced from the ores could have contained significant amounts of arsenic and nickel and so potentially match a large proportion of metal artefacts. To even out the wide natural chemical variation in ores the average ore analysis of the malachite-goethite ores is shown by the larger red square. The minor malachite-only ores are also shown (green triangle symbols) which have lower levels of impurities.

How then does this compare with the existing analyses from the bronze fragments from the mine? These (orange circles in Fig.4) show a remarkable correlation with the average ore analysis. What about the Late Bronze Age copper prill analyses from the smelting residues from Pentwyn? These have lower impurities (green diamond symbols) but are still within the range defined. Taken together a mine-based metal group (large ellipse Fig 4) is emerging with some arsenic outliers but some arsenic will be lost on re-melting for refining or recasting.

The most prominent Middle Bronze Age metalwork in North Wales is the Acton Park assemblage named after a hoard found near Wrexham. This is a period when radiocarbon dating suggests the Great Orme was active. When British metalwork
from the Acton Park period of the Middle Bronze age is added to Figure 5 it is seen to plot in the same area as the Great Orme ores and so this is consistent with the source of the metal being from the Great Orme. (see later). If we look at other pairs of elements (e.g. antimony and nickel) a similar picture is emerging. Great Orme is also characterized by very low antimony levels.

Due to the possibility of overlaps with other ore deposits there is a need for a second independent signature, which can be obtained from lead isotope data. Each ore deposit can have a different mixture of lead isotope ratios and plot in different areas of a graph. This type of study has been widely used in metal artefact, and ore deposit studies around the world. There are four important lead isotopes of lead for this type of work. While lead isotope 204 has been constant since the Earth was formed the other three lead isotopes (206, 207 and 208) are from the radioactive decay of uranium and thorium whose levels vary depending on many geological factors. The isotopic ratios are unchanged by the smelting process. Ideally, an ore deposit will occupy a small discrete area on a plot of these ratios unless there is uranium in the ore deposit then these ratios change after the mineral deposit was formed.

So what does the Great Orme ore isotopic data tell us? Rather than occupying a discrete fixed area on the isotope ratio graph like most metal mines, the Great Orme results stretch over a wide range suggesting there has been some post mineralisation change in the lead isotope levels. This change is caused by the presence of uranium in the mineral deposit which, due to radioactive decay, forms completely new lead isotopes (extra lead 206 and 207) and so affects the plot of lead isotope ratios. The affect on the ratios is greater when the lead level in the copper deposit is low (away from the earlier lead vein). Another factor affecting the ratios is the variable and non-uniform presence of uranium in the deposit. Putting the scientific detail to one side, the overall consequence of all these special factors is give the Great
Orme an unusual lead isotope signature. Isotopic data on the copper prills from the Pentwyn smelting site also show this trend indicating they are consistent with the Great Orme ore source as might be expected. The separate vein(s) of lead ore that crosses the mine has an isotope value in the top right area where most British Bronze Age metalwork also lies (top right ellipse). About half the Great Orme ore data (including the bronze fragments found in the mine) lies in this top right area, possibly because of lead pick-up from the lead vein shifting the isotope values to this area.

Let’s now zoom in on this top right area and look at where the main British and Irish Bronze Age copper mines plot (Fig. 7). The Great Orme mine ore plots separately from the other mines (blue area highlighted) except for an overlap with the Alderley Edge mine ores in Cheshire but that is a small mine that predates the main period of working at the Great Orme mine. We can add to this mine data the metal artefacts for each period in the Bronze Age. If we just look at the Middle Bronze Age metalwork (red squares in Fig. 7) the Great Orme mine was the only British copper mine known to have been still working and there are plenty of metal artefacts that match its ores but also many others, particularly from the SE of England, that match no known British mine and suggest an imported source(s). There is possibly a recycling mixing line between Great Orme and this other source(s).

If we again test whether the Great Orme ores matches Middle Bronze Age Acton Park metal artefacts (Fig. 8) we find (as with the chemical ‘signature’) many have a very close match. Having a match with the Acton Park metalwork is particularly significant as Peter Northover (Lynch 2000) has identified this metal not only over Wales and lowland Britain but also on the continent (see Fig. 9) from Brittany to the Netherlands.
Fig. 7: Lead isotope ratios for Great Orme ores (blue shaded area), other Bronze Age mines and Middle Bronze Age metalwork. Some metalwork (including Acton Park) match Great Orme. Other data suggests another source probably imported.

Fig. 8: Lead isotope data for Great Orme ores, copper prills and bronze fragments from mine plus Middle Bronze Age Acton Park metalwork.
In summary, good progress is being made in linking Great Orme ores chemically and isotopically with particular British Bronze Age metalwork. Contrary to previous papers that claimed the Great Orme ores were low in impurities and so could only produce low impurity metal, this study has found significant levels of arsenic and nickel in the ores. A metal with nickel and arsenic impurities is consistent with the bronze particles from the mine, the Pentrwyn copper prills and more importantly with a substantial proportion of British Middle Bronze Age metalwork particularly the Acton Park assemblage (1500 to 1400 BC). Further work may allow the metal to be identified in other periods of the Bronze Age. The analytical programme on ores, bronze fragments and smelted copper prills is continuing and smelting experiments are planned with Dave Chapman at Ancient Arts. This work should lead to a greater understanding of the importance of the Great Orme mine in the Bronze Age, the ores and the smelting technology being used, the social organization of the mines and the exchange networks within Britain and into parts of mainland Europe.

The current indications are that during a millennium or so of mining (continuous or intermittent) at the Great Orme there were probably a couple of centuries when it was the principal copper source for most of Britain and some metal ended up, one way or another, being exchanged with areas along the continental coast. In cooperation with the University of Gothenburg we are currently looking at data from Denmark to see if we can identify any Great Orme metal amongst their many imported sources. If Great Orme metal can be identified this may indicate a link with the Scandinavian amber trade. All this will help to cast light on the emerging picture of the movement and interaction of people and materials during the Bronze Age that was perhaps much greater than previously realized. There is now general recognition that the Great Orme mine is one of largest Bronze Age mines in Europe (O’Brien 2015).

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