Reconstructing and testing the Pentrwyn pit furnaces.

_Late Bronze Age copper smelting on the Great Orme._

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_Ancient Arts 2013_
Pentrwyn Bronze Age copper smelting site: Reconstructing and using the Pentrwyn pit furnaces

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Summary

Evidence for small-scale copper smelting dating to the Bronze Age has been identified at Pentrwyn, Great Orme. This evidence was in the form of copper smelting debris (copper metal and slags) and three very small pit features. This short paper examines the evidence; records our successful attempt at reconstructing the pit features as small, assaying furnaces and briefly discusses the implications of the results.

Introduction

In 1997, David Chapman of Ancient Arts identified eroding deposits on the Great Orme, Llandudno. These deposits contained fragments of charcoal, shells, bone and metal working debris in the form of small, prills of copper metal (less than 50mm in diameter) with adhering fragments of slag like material. The potential importance of this site was significant as it is located just over one kilometre from the remains of the most extensive Bronze Age copper mine known in the UK. At the time of its discovery and subsequently no associated smelting sites or settlement sites have been found on the Great Orme. Indeed, no Bronze Age smelting sites have been positively identified in the UK.

As a result Cadw funded Gwynedd Archaeological Trust to undertake two excavations (one in 1998 and one in 2011) to recover any surviving remains. A third 'rescue' excavation was undertaken in 2005 by the authors to record and recover information exposed by an episode of severe erosion.

The site seen from the road. The excavations took place on the top terrace. Note the erosion of material.

All that was left of the original terrace, with the road below.
The site itself had been severely damaged in the 19th Century by the construction of a tourist route, The Marine Drive. This road running around the Great Orme’s Head had removed 80-90% of a natural limestone shelf on which the site was located. As a result only a small, rectangular area of approximately 4m by 2m remained in 1997. The eastern side of this area was exposed as a section of deposits overlaying limestone bedrock. It was from this section that the charcoal and metal working debris were eroding. Natural erosion was destabilising this section and in addition sheep and goat activity and use by rock climbers was causing further erosion of the surface above the section.

Below is a brief description of the results of the excavations.

**The 1998 excavation**

This excavation removed an area of 2.2m by 1.8m down to the buff coloured clay that was found across the whole site.

This was overlain by a grey silty/clay (Context 020/028) which contained fragments of animal bone, pieces of metallurgical debris and copper ore. A fragment of shale bangle was also recovered from this layer. The largest feature recorded was a pit (025) which contained fragments of burnt stones, animal bones, marine shells and a whetstone. This pit cut both the grey silty clay layer and the buff coloured clay. It also cut was therefore later, another charcoal rich, shallow pit (031) the lower fill of which produced a radio carbon date of cal AD 1035 – 1285 at 95% probability (Beta-127077) (Hopewell & Jones 1999).
The remains of the hole/pit filled with charcoal rich silt and metallurgical material dated to the Early/Middle Bronze Age.

Seen first in section before excavation (scale 0.2m) and below in plan (marked by the tag) before excavation.

The whetstone (below) found showed several wear patterns, suggesting different uses. Its larger flat surfaces and the side edges show evidence of polish (indicating its use as a whetstone); while the short end edges and the corners show evidence of it being used to hammer and crush some hard material. In places this evidence had been partly worn flat by its re-use as a whetstone. Although this was found in the later pit (025) it might be residual from the earlier layers as the pit clearly cut both the grey silty clay and the buff clay layers.

The whetstone showing battering marks at all corners.
The whetstone: showing crushing and battering damage on ends and edges.

Metallurgical debris was found across the site in all layers excavated. These were sent to The Department of Materials, University of Oxford for analysis. (A full discussion of the results follows the descriptions of the excavations.)

An example of the small size and appearance of the metallurgical debris recovered from the site.
In October 2005, it was noticed that the grey layer identified in 1997 was exposed at the northern, unexcavated end of the site. It contained fragments of reddish clay, charcoal and slag/copper metal material. To prevent the unrecorded loss of this material a small area (c.1m by 0.5m) was cleaned and the metallic debris recorded and removed. This material was found to be eroding out of the grey silty layer identified covering the area excavated in 1998 which produced most of the metallurgical debris.

A distinct patch of yellow silty clay was also identified overlaying the grey silty layer on the western side of the area excavated. This feature was cut by the large post AD 1220 pit (025) found during the 1998 excavation but not fully excavated (Hopewell and Jones 1999). The yellow clay in turn overlaid a small sub-circular feature (later identified as pit 111). This small pit was only partially exposed during this excavation. A second small sub-circular feature was found 100mm to the east of the first (later identified as pit 109). This was fully excavated and the fill retained. Both small pits contained fragments of metallurgical debris; which were retained for analysis. No further excavation took place and the area was recovered with material.
The patch of yellow silty clay cut by the unexcavated Medieval or later pit (on the left). Scale 0.2m.

The two pits 109 and 111 (Pit 111 was only partly exposed and not fully excavated at this time). Pit 111 was overlain by the patch of yellow silty clay. Scale 0.3m.
The 2011 excavation

With erosion of the site continuing, in 2011 Cadw funded a second excavation of the remaining deposits. Ancient Arts Ltd undertook ‘on site’ and later ‘off site’ wet sieving of all the material excavated on the site. This excavation recorded the two small pit features (109 and 111) in further detail. These features were sub-circular in plan, almost vertically sided but tapering slightly at the base. Feature 109 was 100mm in diameter and 100mm in depth and Feature 111 was 90mm in diameter and 150mm in deep (Smith 2012, 5).

Feature 109 had a notable slot cut into the top of the cut (on the west side) which gave it an unusual keyhole appearance. Feature 111 also had a similar keyhole appearance and in addition had a modelled raised rim or collar around an its top with a gap or slot cut into its western side. (see below). Feature 109 lacked a definite collar but it had suffered greater damage from erosion than Feature 111. Feature 111 had also been sealed and protected by a distinct light coloured patch, Context 129, whereas the top of Feature 109 had already been partly exposed when the 2005 excavation took place (Chapman and Chapman 2005). However, a surviving arrangement of stones around the south edge of 109 may represent the remains of a clay collar (see below).
The fills of the pit features were slighter darker and more charcoal-rich than the general layer (Context 108) into which they were cut and a number of copper metal prills had been retrieved from them when they had first been exposed in 2005. Charcoal from the fill of pit 109 produced a radio carbon date of 930-809 cal BC with a 94.6% probability (SUERC-44867). (Two other date were obtained for the grey silty layer just to the west of the pits; they were 929-812 cal BC and 1005-842 cal BC (Smith pers com)).

Reconstructing and testing the Pentrwny pit furnaces.

A close-up of Features 109 and 111, showing the slots and 'collar' feature.

Initially, due to their small size and lack of evidence for exposure to high temperatures, the features were not identified as possible furnaces. However, previous experimental work smelting copper in bowl furnaces has shown that the archaeological evidence which might be expected to be found, such as burnt clay or vitrified soils, were often not produced by small-scale experimental furnaces (Chapman pers. com.). Also, the original metallurgical analysis undertaken after the 1998 excavation (Northover & Salter) concluded that the smelting on the site was small-scale, perhaps assaying rather than large scale smelting.
With this evidence in mind we undertook a series of experiments to test if these features could indeed be the remains of small assaying furnaces.

**Methods**

There is very little archaeological evidence of copper smelting in mainland Great Britain from before AD1500. However, previous experimental work has shown how it is possible to smelt carbonate ores using bowl or pit furnaces, clay tuyeres and leather bag bellows (http://www.youtube.com/watch?v=8uHc4Hirex). So using this previous work as a starting point we set out to reconstruct the Pentrwyn features (pits 109 and 111) and then attempt to smelt copper with them. (Not enough of the Early to Middle Bronze Age pit found in 1998 survived to reconstruct to include in this project.)

**The ore**

One of the most important elements involved in this experimental project was to ascertain the type of copper ore that was being smelted at Pentrwyn. This is important as primary sulphide ores and secondary carbonate ores are smelting slightly differently. Sulphide ores are roasted first to burn off impurities and a flux such as quartzite, feldspar or limestone is used in the smelting process. Carbonate ores do not require pre-smelting roasting or a flux and can be smelted at relatively low temperatures.

Analysis of the original metal working debris found in 1998 was based on only 18 small fragments from the site. The condition of the material was described as 'not good, as it has suffered from 3500 years of corrosion aided by salt spray' (Northover and Salter, 2). Also the small size of the individual pieces meant that in some samples 'only very limited areas of material' (Ibid.) were suitable for analysis. The samples contained slag material, fragments of copper ore and fragments of metallic copper.

Using lead isotope analysis Northover & Salter felt that they could make a direct connection between the fragments and the Great Orme. High concentrations of uranium and thorium are found in the minerals of the Great Orme and this was indeed the case from the Pentrwyn samples, so that 'within the limitations of available lead isotope data' (Ibid., 9) they felt that the copper prills from Pentrwyn could be linked to the mineralisation of the Great Orme.

The slag was described as 'inhomogeneous' in nature suggesting that the 'charge within the hearth/furnace never became fully fluid' (Ibid., 8). So the metallic copper was only partly smelted and not refined into its massive form. Hence it was found as small prills and not as a large conjoined mass. Northover & Salter (Ibid., 8) agreed with Hopewell and Jones that these copper prills/slag fragment could then have been crushed (removing much of the slag material and re-smelted to form purer, larger fragments).

The high proportion of copper sulphides present in both the metal and slag together with the remnant ore fragments, 'indicate that the ore used was rich in sulphide mineral' (Ibid., 8) and derived from chalcopyrite. However, the primary ores exploited on the Great Orme were carbonate ore such as malachite. Dutton & Fasham have suggested that high-quality carbonate ore were exploited during the Early Bronze Age 1885-1465 BC and 1735-1440 BC (Dutton & Fasham, 1994, 284). They argue that these could have been smelted at relatively low temperatures and would have produced minimal amounts of slag. They go on to suggest that later re-working of the mines (1428-975 BC) was
However, the metallic debris from the 1998, 2005 and 2011 excavations consisting of over 500 fragments is currently being analysed by Alan Williams (University of Liverpool). Whose current assessment is:

*The current evidence suggests that predominantly oxidised ores were mined during the Bronze Age at the Great Orme mine. The principal ore minerals would have been malachite with occasional azurite, usually mixed with substantial amounts of goethite (hydrated iron oxide containing some copper), all derived from extensive weathering of the primary chalcopyrite mineralization. Other minerals present include calcite and dolomite. However, in some areas of the Bronze Age workings, particularly in the harder sides of the veins there would have been some residual unconverted chalcopyrite within the oxidised ores. The occasional traces of sulphide minerals found in the Pentrwyn smelting residues may just reflect this situation rather than indicating that sulphide rich ores were being smelted.*

(R A Williams pers. com.)

As fragments of malachite ore were visually identified at the Pentrwyn site during the excavations and that the recent metallurgical analysis is based on a much larger sample than Northover and Salter examined indicates that malachite (containing residual unconverted chalcopyrite within the oxidised ores) was most likely smelted at Pentrwyn it was decided that malachite would be smelted during the experiments.

**The tuyère**

A simple tuyère was made from a mix of clay and chopped plant fibre (dung could also have been used). It was then dried on a small fire. Previous experimental work has shown that it is not necessary to partially fire or even fully fire the clay so that it becomes a true ceramic.
The diameter of the *tuyère* was determined by the width of the slot from the Pentrwyn features. This was approximately 50mm which allowed for a diameter of approximately 15mm for the internal air channel.

A pit was then excavated 100mm in diameter and 110mm in depth. This was found to be the smallest hole it is possible to excavate easily with your hand. Any smaller and it becomes difficult to remove the fill.

A small slot was then dug entering into the pit on one side. This was to allow the *tuyère* to enter the furnace (and give the pit a distinct *keyhole* shape similar to those recorded at Pentrwyn). Its depth was determined by the evidence from Pentrwyn where the slot did not continue straight down the side of the pit but was only visible near the top of the pit.
The excavated pit with tuyère slot and the tuyère itself. Scale 0.2m.

The fill of the excavated pit was then mixed with water and used to form a collar similar to the one identified on Pentwyn Feature 111. It became clear that this collar not only helps hold the tuyère in place but most importantly allows the furnace and the tuyère to be sealed when the turf cap is placed on top. Once working the whole furnace, including the tuyère, has to work as a pressurised system to smelt the ore. This collar acts as a washer between the top of the furnace and the turf cap. Without this seal it is very difficult to produce a back pressure within the furnace and without this back pressure the temperature within the furnace would level off before it reached the temperatures needed to smelt the copper.

Making the 'collar', note the turf cap in the background and the kindling ready to start the smelt.
The angle of the tuyère was determined by the shallowness of the slot from Pentrwn Feature 111. We had initially intended to use leather bag fellows to fire the furnace, but these are usually laid on the ground horizontally to the furnace and after a number of readjustments it became clear that the tuyère would have to enter the pit at a steep 60 degree angle. At this angle bag bellows would not work and it also became clear that the bag bellows would produce far too much draft for such a small furnace. This led us to the conclusion that a blow pipe was a more likely source of air for the original furnaces.

Therefore, we decided to use a blow pipe to draft the furnace. Wooden blow pipes can easily made from straight pieces of elder branches which have been split open, the pith removed and tied back together leaving a long, hollow tube. Clay was then added to the mouth of the tuyère to form a seal to help pressurise the system.
Malachite ore was then crushed to dust using a stone hammer and mortar and the furnace lit using a kindling of twigs (birch) with charcoal added. Subsequently some of the charcoal fragments from the 2011 excavation of pit features from Pentrwyn have been identified as holly, this would have made ideal kindling (Smith pers com).

Using the blow pipe the charcoal was set alight and a *turf cap* (simply a piece of cut turf) placed over the furnace. Turf makes an excellent refractory insulating material because it can withstand high temperatures and works just like *ceramic fibre* in a modern foundry.

During the 2005 excavation of the site a discrete, light coloured context (129) was recorded sealing Feature 111, excavated and retained. This was identified as a piece of possible buried turf perhaps representing the remains of a *turf cap*.

The crushed ore was added by hand onto the red hot charcoals and the smith started rhythmically blowing down the pipe. Now that the furnace is sealed by the *turf cap* this allows the smith to build up and control the pressure inside the furnace and therefore to control both the atmosphere and the temperature. It was observed that when using the blowpipe it was possible to physically feel the pressure changes within the furnace (from the resistance during blowing).

Interestingly it was also noted that the rhythmic blowing produced a feeling of euphoria and light headiness in those using the blowpipe!
The copper ore at the start of its journey down through the reducing zone of the furnace.

The small size of the furnace meant that a only comfortable and sustainable amount of air had to be blown into the furnace to produced the required pressure. Therefore, the size of the furnace matched the lung capacity of a single smith. To control the pressure within a larger furnace would have required more than one blow pipe or a larger set of bellows, such as a bag bellows. So this size of furnace was designed for a single blow pipe as the physical remains of the single slot suggested.

The smelt under way. Note that the ore has now moved down into the hottest part of the furnace.
The smelt continued for 90 minutes with small amounts of further charcoal added when required. The charcoal is regularly tamped down to compact it and thereby reduce any air voids present. Wet charcoal and charcoal dust are also added. These factors created a reducing atmosphere (a carbon monoxide rich atmosphere) within the furnace which is needed to smelt the copper ore. In simple terms smelting takes place when the carbon monoxide produced by the burning charcoal bonds with the oxygen in the ore, this produces carbon dioxide and copper metal.

It is possible to see when this reducing atmosphere has been achieved. By removing the turf cap the flame from the furnace will have changed from a yellow/orange appearance to a purple/oily flame. This is called a sick flame.

After 90 minutes the contents of the furnace were then carefully removed and washed.
Small metallic copper prills are visible, some metallic material is still adhering to slag. Also visible are fragments of the kindling reduced to charcoal but still identifiable as small twigs.

Small metallic copper prills were quickly visually identified and retrieved. Some were adhering to slag fragments (which could have been partly removed by crushing). The assemblage of metallic debris and prills were visually very similar to those found at Pentrwyn.

Copper metal that has started to become fluid will form small prills. To test at what stage the other ore/metal was at we crushed the material with a stone. If it was only partly smelted (known as blister copper) it will be reddish in colour but will fracture like a heated stone. If this was the case it could be simply returned to the furnace and the smelt be continued for a further half hour. If it does not crush easily or fracture then the material is copper metal and the smith knows that has smelted a suitable copper ore.

The whetstone found in 1998 (in the later, post AD 1220 pit but possibly residual for the earlier Prehistoric activity) does have clear evidence of having been used as a hammer and as a pestle, to crush some hard material. This could have been used for crushing the ore at the beginning of the smelt or perhaps to break up or test the metallic material at the end of the process.
Results and discussion

The furnace

Once it had been emptied the interior of the furnace was examined. There was no vitrification or reddening of the soil sides of the pit. Some charcoal fragments remained inside the pit and littered the area immediately around the furnace forming a dark, dirty working floor (very similar to the grey layer associated with much of the metal working debris at Pentrwyn). Fragments of copper ore dropped during the charging of the furnace were identified around it, as were small copper metal prills/slags where having been missed during the initial visual retrieval process. Again this reflects the debris from the working floor (grey layer) at Pentrwyn.

The collar remained intact, with some minor damage where the tuyère was removed. Although this is essentially just dried soil and is therefore quite delicate replacing the turf cap after use (as what appears to have happened at Feature 111) would protect this delicate feature very well.
Features 109 (top right) and 111 (bottom left) showing the tuyère slots and collar. Scale 0.2m.

Reconstructed pit furnace after the smelt. Scale 0.2m.
**The tuyère**

At the end of the experiment the tuyère was also examined. The end at which the blow pipe entered had suffered some damage (this occurred during a personnel change over on the blow pipe) but his had been quickly repaired with some wet clay. The furnace end had small amounts of vitrified soil/charcoal adhering around its very end (where it would have been resting in the hottest part of the furnace). This end also appears to have been partly fired by the heat within the furnace and is harder than the rest of the tuyère.

![The reddened and slightly vitrified furnace end of the tuyère. Scale 0.2m.](image)

As part of the on-going experiment it was left on the ground near the abandoned furnace. Within two weeks it began to noticeably deteriorate with mould appearing on the surface and this showing signs of structurally decaying. It is anticipated, based on previous experiments that most of the tuyère will disintegrate quite quickly leaving just the small part of the semi-fired end, which itself may deteriorate into smaller fragments.

![The turf cap showing signs of burning and drying. Note the green copper ore debris in the centre and part of the damaged tuyere on the left.](image)
The turf side of the *turf cap* showed no visible signs of heat damage. While the under side showed signs of burning and drying (to a depth of 25mm) but no sign of any soil vitrification.

Future analysis needs to be undertaken on this *turf cap* and on Context 129, the possible buried turf found in 2005 at Pentrwyn, to determine if either or both are heavily contaminated with the chemicals or trace elements associated with the smelting process. It would also be very valuable to examine Context 129 for the presence of any charred root remains.

It is interesting to note that environmental evidence from the 1998 excavation identified the presence of charred *Poacea* (grass) remains, including rhizome material (Caseldine and Barrow, 2). These came from the fill of the post AD 1220 pit (Context 25). However, it was felt that '...some, if not all of the remains, are possibly residual and prehistoric in date' (Ibid. 1). The 2005 excavation showed that this pit (Context 25) cut the possible buried turf cap (Context 129) and therefore the charred grass rhizomes may indeed have originated from this earlier context.

![Image of Context 129](image)

*The light coloured Context 129 as exposed during the 2005 excavation. It sealed Feature 111. Note Pit 25 cuts 129.*

The furnace pit was backfilled using the debris in the immediate vicinity, the *turf cap* placed over it and left. It is intended to continue to monitor and record its decay.
Conclusions

This experiment has shown that the two pits found at Pentrwn can work perfectly and elegantly as small-scale assaying furnaces. The physical evidence from the excavations: the size of the features, the remains of the collar, the tuyère slots, the possible remains of the turf cap, the whetstone and the metallic debris all compellingly point to the pit features being small-scale assaying furnaces. The experimental work has also shown that features often expected to be found on smelting sites such as vitrified clays, crucibles and large amounts of slag material would not have been produced or needed on this particular activity.

As assaying furnaces they are efficient and very well designed. The presence of the collar shows that the smith understood the need to seal the furnace to build up and maintain the internal pressure of the furnace to smelt the ore. If the intention was to test the ore, to ensure that it was copper ore or that it was of suitable quality, then there would be no reason to smelt any more ore than necessary to ascertain this. These furnaces could be worked by a single person, would use very little charcoal (0.9 litre of charcoal was used during the experiment) and could be done relatively quickly and discreetly.

The metallic material produced by the experiments closely mirrors the metallic remains found at Pentrwn and indicate that full, fluid smelting of copper ore was not undertaken on this small part of the site excavated (barring in mind that most of the original shelf on which the site was located was destroyed in the Nineteenth Century and the full extent of the original site is not known). The fact that so many copper prills were left on the site suggest that the smith was more concerned with the assessing the quality of the ore (or indeed if it was ore) rather than retrieving as much metal as he could.

The lack of obvious and severe heat alterations to the soil forming the furnaces, the lack of surviving crucibles and tuyères may have broader implications for the future identification and excavation of low temperature copper smelting furnaces. Previous experimental work using large, repeatedly fired earth and dung above ground furnaces to fully smelt carbonate copper ores has shown that once abandoned and left exposed to the weather they will completely dis-integrate and wash back into the ground leaving only a few very small fragments of reddish clay and charcoal within period of a year. Careful retrieval of the metallic copper produced by these furnaces using visual identification and a simple panning technique of furnace contents leaves very little accidental loss of copper metal (it is even possible to retrieved and re-use any remaining charcoal). It cannot be over emphasised that the Pentrwn site was only identified as a smelting site because of the careful retrieval of very small metallic debris from wet sieving every bag of soil excavated. Only a few pieces of this debris were identified by eye during excavation and this only after the excavators were made aware of its probable presence.

In addition to Features 109 and 111 there were the possible remains of two other furnace pits (both badly damaged or destroyed) just to the south-west (see illustration 1) as well as, the remains of Feature 021 (dated cal BC 1580) from the original 1998 excavation which may also have been the remains of another small furnace. Are we looking at an assaying site that was regularly re-visited over a long period of time and not a one off event?

The location of the site also hints as its use as an assaying site. It is located well away from the Bronze Age mines at Pyllau. (To the North of the site is the copper ore washing site at Ffynnon Galchog/Porth yr Helig. However, the one date from this site is cal AD 720-740 and 680 – 960 (Lewis 1993, 10) and therefore, not contemporary with Pentrwn.) You would expect an assaying site to be located near to the ore source. It is possible that there is an as yet unidentified Bronze Age mine near the site, but the Pentrwn site’s location is also very well hidden (it is only visible from the landward side from
approximately 15-20m from the North). It is much more visible from the sea; as is the natural harbour of Pigeon's Cave accessible just below the Pentrwyn site. This Cave was also the site of the discovery of the only Bronze Age hoard so far found on the Great Orme. This hoard included two incised, lock-rings, thought to be made of Irish gold. The fragment of shale bangle found at Pentrwyn during the original excavation in 1998 also hints at the Great Orme’s position within wider trade networks.

Are we looking at outsiders coming in by sea, assessing ores near their anchorage before leaving with larger quantities of ore and smelting the ore elsewhere?

No evidence for large-scale smelting has yet been found on the Great Orme, perhaps none took place there. The availability of the large amounts of charcoal needed for large-scale smelting could well have been a major issue even with a locally organised coppicing regime. Perhaps only small-scale assaying took place on the Great Orme with larger-scale smelting taking place nearer to better sources of charcoal.

**Bibliography**

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We would also like to thank Andy Lewis, Danny Dutton, Peter Crew, David Jenkins and all at the Early Mines Research Group for all their support and encouragement over the years.