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The Beginnings of Metallurgy in South-West Britain: Hypotheses and Evidence

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Abstract
This paper describes the surviving material evidence of prehistoric mining and smelting in light of recent experience in the British Isles. The paper then discusses the apparent lack of evidence for the remains of prehistoric metal production in the south-west of Britain, and explores some of the ways in which such evidence could be established.

INTRODUCTION

The usual evidence for ancient metallurgy in Britain, as elsewhere, has been the surviving metal artefacts rather than the mines or smelting places, although this situation is now fast changing as more and more early mining sites are recognised and become the subject of detailed archaeological investigation (Crew & Crew 1990, O'Brien 1994, Dutton and Fasham 1994, 245-86, Ford and Willies 1994, Craddock 1994, 69-83 and 1995, 37-61, Timberlake 1992). However little or no mining activity has as yet been proven from the south-west in prehistory (Sharpe 1992), even though the abundant near surface deposits of copper, gold, tin and lead would have been very obvious and attractive to early prospectors. The latter view is reinforced by the very rapid and almost total adoption of bronze in Bronze Age Britain at the end of the 3rd millennium BC, once the tin deposits had been discovered, and the unusually consistent and high tin content of British bronzes when compared with contemporary bronzes elsewhere. The most obvious explanation for this pattern of bronze usage is that large tin sources were being exploited and the only viable sources for such large scale and sustained production are those in the south-west of Britain (Penhallurick 1986, Budd *et al* 1994, 518-24).

However, the deposits are likely to have been very easy to work and this could account in part for the lack of the more obvious evidence found elsewhere. Much of the tin will have come from workings in placer deposits which are very difficult to accurately define or to date. The geology of the south-western Peninsula is different from the rest of the British Isles, and it is perhaps especially significant that it was the one area to escape glaciation which may mean that large areas of very easily worked primary surface deposits of both copper and tin were present which could have been worked by the first miners without recourse to the methods necessary to work the true hard rock deposits of the remainder of the British Isles.

Before discussing the forms of evidence which could be indicative of early working it is necessary to consider how metallurgy could have been introduced into western Europe and the British Isles.

Paradigms for the inception of metallurgy into western Europe and the British Isles

The earliest metal artefacts from Britain are currently dated to the second half of the third millennium BC, broadly contemporary with the (calibrated) radiocarbon dates from the mines at Ross Island (O'Brien 1994, 230-1), although the earliest dates from mainland Britain are currently no earlier than the beginning of the second millennium BC (Craddock 1994, 69-83). This supports previous hypotheses made on the basis of the trace element analysis of the earliest copper artefacts that the south-west of Ireland was the probable source of the earliest metal used in the British Isles (Northover 1980, 63-70). At present however we still have little direct field evidence upon which to base the inception of metallurgy in mainland British, and this has some bearing on the evidence to be expected from the south west.

It is however clear that metallurgy commenced in the British Isles with copper and gold, only to be joined by tin, in the form of bronze, after several centuries around the 22nd century BC at the end of the 3rd millennium BC, and lead much later at the end of the Middle Bronze Age (Needham and Hook 1988, 259-74), apart from the recently discovered lead beads from an Early Bronze Age burial in Scotland (Hunter and Davies 1994, 825-30). Silver was apparently not used before the very end of the Iron Age. This sequence which is repeated in much of western and central Europe is very different from the development of metal usage in the eastern Mediterranean and Middle East where copper and lead were the first metals to be exploited, followed at a very early date by silver and only latterly gold. This argues against a diffusionist model for the spread of metallurgy through Western Europe, and it should also be noted that extractive metallurgy could not spread continuously through Europe as agriculture may have done millennia before, necessarily it could only develop where the relevant ores occurred, often separated by hundreds of kilometres. It is also significant that the first two metals to be exploited were copper and gold, the two metals which occur widely in their native form. From this and other evidence, considered in more detail elsewhere, a hypothesis has been developed for the spread of metallurgy that was based on local discovery but possibly initially inspired by the appearance of exotic metal artefacts of copper or gold, which could be recognised as a local resource in the areas, such as the south-west of Britain where they occur as native metals.

The situation with tin and by extension, bronze, is especially important to any study of metallurgy in the south west. Bronze was in very limited use in the Balkans in the fifth millennium BC (McGeeham-Liritizis and Taylor 1987, 287-300), and seems to have come into general, though not exclusive, use in Anatolia and Mesopotamia during the 3rd millennium BC, with at least some of the tin coming from the mines at Kestel in southern Anatolia (Yener *et al* 1989, 200-3). If metallurgical technology had diffused from the Middle East with miners and smiths then one would have expected the same suite of metals including bronze to have been exploited. However as noted above the first metallurgy in the British Isles was based on copper and gold with tin bronze only appearing some centuries later, clearly the first metallurgists in Britain had no realisation of the significance of the huge surface deposits of cassiterite in the south-west, and yet it is inconceivable that these were not thoroughly investigated and worked for the gold they contained. It could be postulated that occurrences of tin were so rare that during the spread of metallurgy across Europe recognition of the principal mineral, cassiterite, became lost and with it the knowledge of making bronze. This argument is actually difficult to maintain on closer examination of the frequency of Western European sources of tin (Penhallurick 1986), the Balkans (McGeeham-Liritizis and Taylor 1987, 287-300), and central Europe (Bouzek et al 1989, 203-12). The few precocious bronzes in the central Balkans are linked plausibly by McGeeham-Liritizis and Taylor with the small cassiterite deposits of Mount Cer in the same region, and they believe this to be an indigenous development 'that involved experimentation with the minerals of copper lead and tin'. Something very similar could have taken place in the south-west of Britain.

Thus the appearance of metal artefacts in Western Europe could have inspired the local collection of native metal, copper and gold, to be followed in the case of copper, by the smelting of the metal from the ores in which the native metal was found. The steps which could have led from the use of native to smelted metal have been discussed elsewhere (Charles 1985, 21-8, for example), but if this postulated development is correct for Britain then the transition must have been very swift because no items made of native copper have ever been identified from the British Isles, and few are likely to exist. This can be said with some certainty even for copper that has been molten, as native copper tends to be of high purity, whereas copper smelted under primitive conditions tends to be very impure. Inspection of any of the numerous analyses of Bronze Age copper or bronze artefacts reveals very few potential candidates for native metal.

Within western Europe metallurgy was traditionally supposed to have been spread by the Beaker Peoples (so called because of the distinctive pottery drinking vessels found in their burials) during the later 3rd millennium BC. This hypothesis and even the existence of the Beaker People has been challenged, but the early mines at Ross Island are associated exclusively with Beaker pottery, resurrecting the former perception of them as wandering herdsmen and metallurgists.

Further evidence for the local development of metallurgy in Western Europe comes from the patterns of prospection and early exploitation that are found in Britain. Thus the local prospectors searching for copper and copper ore found them in amongst the prolific lead deposits of central Wales, and almost every scrap of copper mineral was removed but the lead ore in which the copper was found was ignored.

Gold would have been found and obtained from the secondary deposits, notably in the river gravels. The sources in the mountains streams of the Wicklow Mountains of Ireland do seem to have been of some importance in the Bronze Age, but it should be stressed that there were many other potential secondary sources, especially in the river gravels of the south west of England (Penhallurick 1986, 160-3, Camm 1995). We must assume that over time all of the likely gravels would have been panned for gold. The amount recovered from the south-west is unknown but undoubtedly quantities of the dense, black cassiterite sands and pebbles would have also been retained along with any gold in the pan. Cassiterite does not look especially promising but the density (typically between 6.8 and 7) would have excited the interest of any prospector. A simple trial smelt on a block of charcoal would have produced metallic tin directly. The important point is that for centuries the potential of the massive surface deposits of easily won cassiterite all over the south west was not realised. Yet almost a thousand years earlier in Anatolia very low grade primary deposits of cassiterite were being painstakingly mined.

Thus in Britain we have the scenario of the first miners working through major lead deposits for minor amounts of copper, and through the tin deposits for even less gold. They were searching for the two metals they could recognise, in ignorance of the potential of the discarded ores that formed the majority of the deposits.

FIELD EVIDENCE FOR EARLY EXTRACTIVE METALLURGY

The consensus of opinion is that some exploitation of the abundant copper and tin ores of the south-west is very likely to have taken place in prehistory, yet very little material evidence for non-ferrous metal production has yet been recognised (Sharpe 1992, 35-40). In this section some of the principal evidences for early metal production are outlined with especial reference to the south west.

COPPER AND HARD ROCK MINING

The stone hammers

The most common and obvious indicator of early mining elsewhere in the British Isles, and indeed in Europe and beyond are the stone mining hammers. All the mines that have been investigated in the British Isles were first identified by the presence of the hammers, and only subsequently was the Bronze Age date for these mines confirmed by radiocarbon dating (Ambers 1990, 59-64, revised in Craddock 1994, 82-3). Here we must be very clear what has been established: all stone hammer workings so far dated are of Bronze Age date, it does not necessarily follow that all Bronze Age mines were worked with stone hammers.

In Wales for example the link between the first reports of hammers at a mine and its excavation is clear. The stone hammers were first mentioned when the mines were reopened in the 18th and 19th centuries in a variety of mine reports and guides, and these were included in the major geological surveys in the early 20th century, such as those conducted by O.T. Jones (1922) in Wales (It is noticeable that the corresponding volume for the south-west of England carries no such reports [Dines 1956]). The Welsh reports were carefully studied by Oliver Davies and latterly by the Early Mines Research Group and sites were chosen for further exploration on the basis of the reported presence of the stone hammers. Thus one could argue that a possible reason for the apparent absence of the stone hammers in the south-west was because the equivalent recording never took place whilst the mines were in operation in the more recent past. This would seem to be a non-starter as antiquities associated with early mining operations in the south-west were clearly of interest to many of the miners there and were carefully recorded by antiquaries such as Borlase from the 18th century on (see Penhallurick 1986 for a very complete record of the finds made in the early tin workings, for example, and Sharpe 1992).

On the mine sites where the hammers are found in the British Isles they are generally very prolific and thus could not be overlooked, however at some ancient mines, notably Timna, in Israel, (Rothenberg 1972) and Kestel, in Turkey (Willies 1992, 241-7) only a very limited number of true mining hammers have been found. In the mining experiments conducted at Cwmystwyth in 1989 the antler tools functioned so well that we tried using them alone against the fireset rock

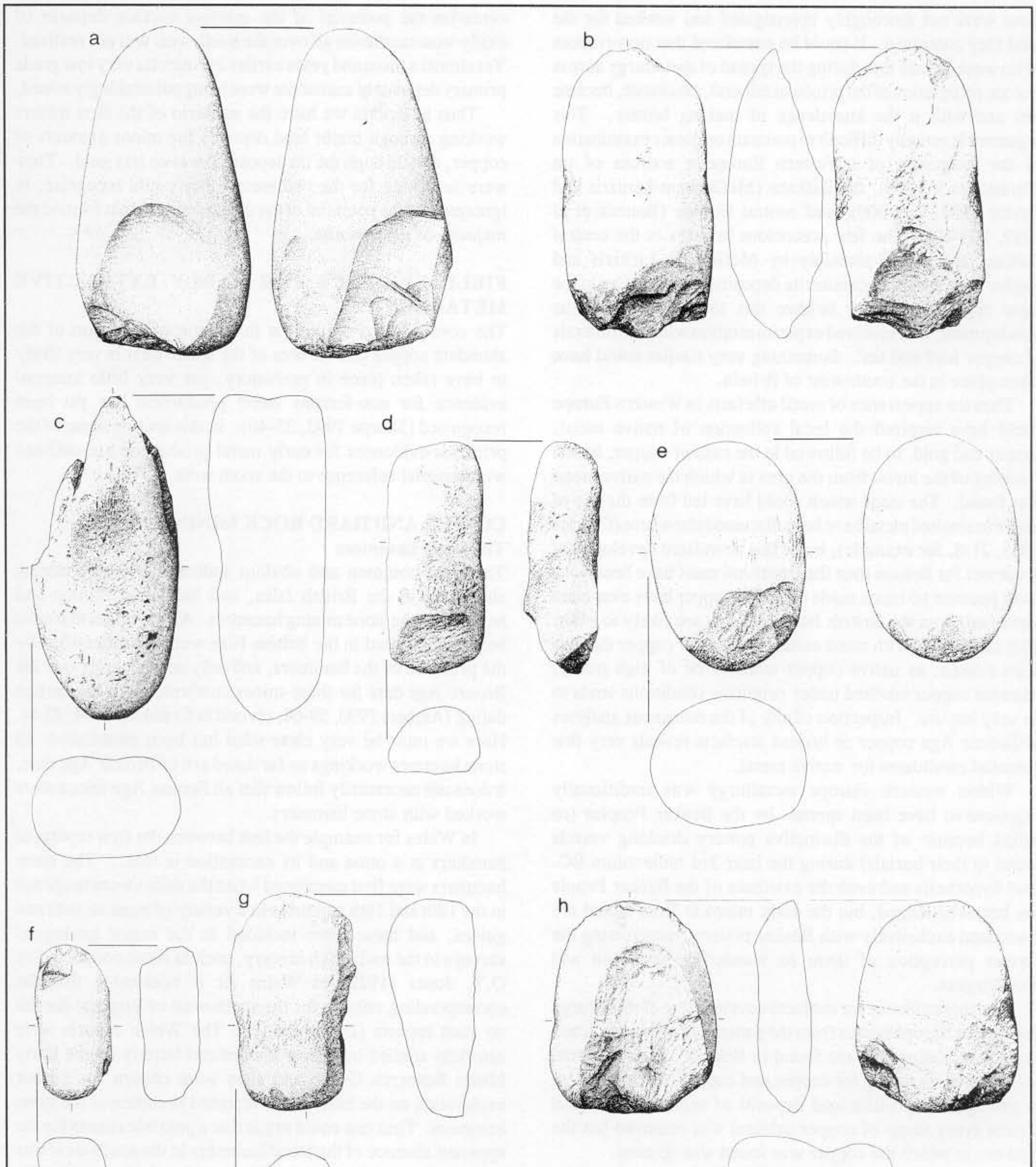
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Fig. 1(opposite) A selection of stone hammers.

a. Cwmystwyth. This is an unmodified hammer used only on the broad end. A stone of this shape needs no notching. Provided the hammer is used only with an underarm swing the stone becomes more firmly bedded in its hafting with each swing. A stone of this shape rarely has much evidence of reuse as a hammer. Experiments to use the narrow end required a very deep notch, and the resulting hammer was not well balanced.

b. Cwmystwyth. The hammer bears the marks of very heavy use at both ends. The first use was on the top end, probably without notching. There are two side notches, one of which goes over the edge of the large flake broken from the top, as does the pecking in the centre. The small flake just below cuts through this pecked area, and so is associated with a later use on the lower end, after rehafting evidenced by the pecking. There are also two small areas of abrasion which may be associated with wedges.

c. Cwmystwyth. This hammer has had three uses. The top end has done heavy work and is badly broken. The lower end bears some marks of pounding or crushing. The flat sides made it suitable for use as an anvil. There is one main hollow and another very slight depression below it. There are now no indications of hafting.

d. Cwmystwyth. A narrow pick-shaped stone with one end considerably more used than the other. The two patches of use on the girth are likely to have occurred during reuse as a hand-held hammer, either to drive in wedges, or to crush ore. The smaller areas of pecked surface on the side and back, could be for hafting.

e. Parys Mountain. This stone has been slightly used on one end only. The intermittent band of abrasion around the girth may have been to assist hafting, but is more likely to result from hammering the hafting into place.

f. Parys Mountain. A small stone used on both ends and probably hand-held. The wear is quite heavy indicating mining although the shape would be suitable for an ore crushing tool.

g. Parys Mountain. A much used cobble, it has wear on both ends. After the stone split the notch and pecking were added and the hammer rehafted and used again on the top end; the wear can be seen extending over the broken surface on the reverse.

h. Cwmystwyth. This hammer was made from a spall from a larger hammer. It has a notch on one side and slight pecking on the broken surface on the opposite edge. It was then used at both ends.

j. Cwmystwyth. Stone hammer much used for heavy battering of hard rock. There is no modification for hafting and it was used only on the broad end. Subsequently reused as a mortar for crushing ore.

k. Llancyfelin. Stone hammer reused as a mortar.

and 'This proved to be extraordinarily effective and several hundred kilos were removed without recourse to hammers' (Timberlake 1990a, 53-4). Thus early mines even in hard rock areas did not necessarily rely on stone hammers. However the tools are so ubiquitous in primitive mines from around the world, that it does seem surprising that so few have been found in Devon and Cornwall.

The hammerstones from the British Isles are either of river or beach cobbles of the locally available hard rock. They tend to weigh between one and five kg, although there are many small examples weighing only a few hundred gms, suitable for working in very confined spaces or breaking the ore at arm's length, deep inside vugs, the narrow crevices which are quite common in all vein systems. There are also much larger examples, right through to 'monster' hammers from Great Orme's Head which can weigh up to 30kg (Jenkins and Lewis 1991, 151-61). These are far too heavy to have been hafted as a hammer and must have been held in a cradle and swung at the rock face.

A large number of flakes from hammers which have fractured in use are usually found together with the hammer stones themselves. Sometimes the flakes bear evidence of reuse, hafted as small narrow hammers (Fig. 1h). It has been suggested that they could have been used as wedges or gads, but recent experiments by the Early Mines Research Group showed they were not at all suitable for opening up cracks in the rock. Antler tines cut from the antler picks or wooden wedges and the 'pry sticks' found at Mt. Gabriel (O'Brien 1990, 279; and 1994, 148) make far better wedges.

All the hammers bear very characteristic marks of rough battering, often accompanied by quite major fractures at one or both ends. A selection are reproduced here to illustrate some of their diagnostic features (Fig. 1a - k). The wear is indicative of heavy shock during use, and very different from the much smoother, finer abrasion found on crushing stones and mortars.

The recognition of the difference between the two patterns of wear is important, as stone hammers and anvils for crushing the mined ore are likely to have been in use for much longer than the hafted hammers used against the rock face (Thorburn 1990, 43-6). Some of the mining hammers bear marks of heavy abrasion on their girth which may be the result of reuse either as hammers for driving in the gads or for crushing. Figure 1d, for example would have made a good flat crushing, or bucking hammer, although there is no evidence of the distinctive dimple in the centre on this or any other stone mining tool so far recovered from the British Isles.

It seems probable that the hammerstones for use directly against the rock face were almost always hafted. Experiments made using them held directly in the hand resulted in considerable shock to the arms and damage to the skin of the hands, although hand held hammerstones could be used perfectly well to drive in wedges of antler or wood (Pickin and Timberlake 1988, 165-7). Some of the hammerstones could be securely hafted without modification of the stone (Fig. 1a), but the majority would have needed some modifications, depending on the shape of the stone itself. The hammers from Alderley Edge, Cheshire, usually have a deep continuous groove pecked around the middle, presumably for a rope or possibly withy handle (Plate 1) (Gale 1990, 47-8). These grooved hammerstones are also found at the rather earlier mine of Ross Island in Ireland but are otherwise quite rare in the British Isles, although quite common on early mining sites elsewhere, such as the south of Spain for example (Rothenberg

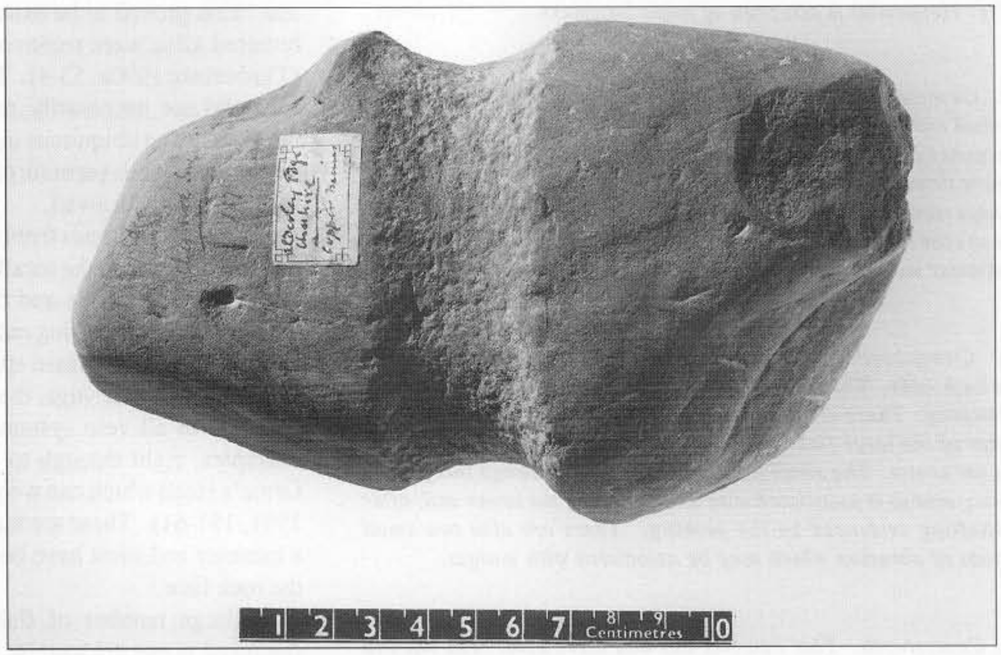

Plate 1. Grooved stone hammer typical of those from Alderley Edge, Cheshire. Now in the British Museum.

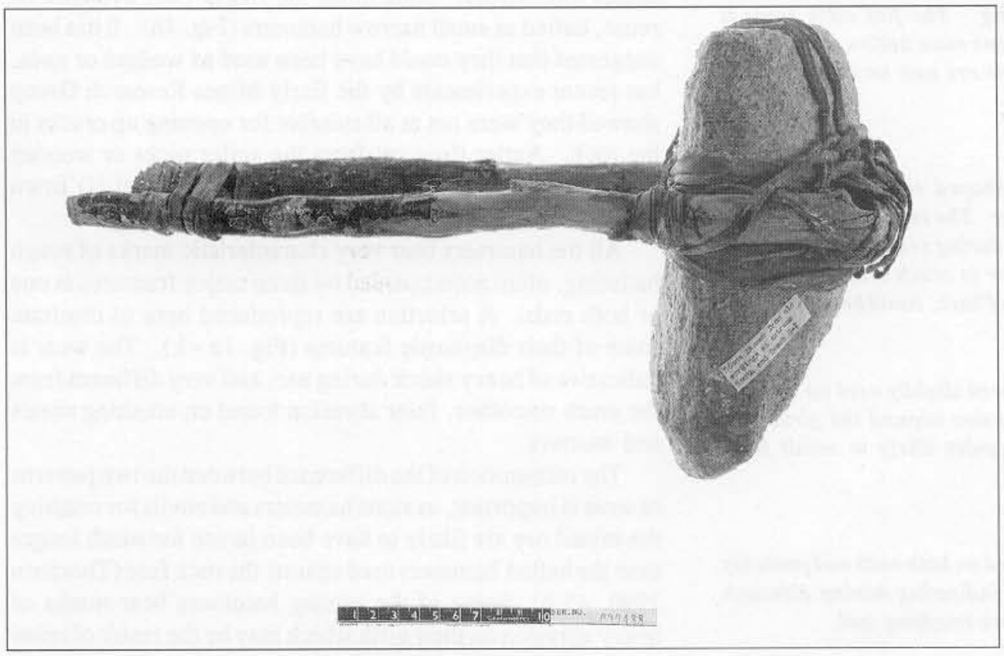

Plate 2. Stone hammer from Chuquicamata, Chile. This hammer retains its original handle and rawhide bindings intact (We are grateful to Dr W. Wray for permission to publish the hammer here).

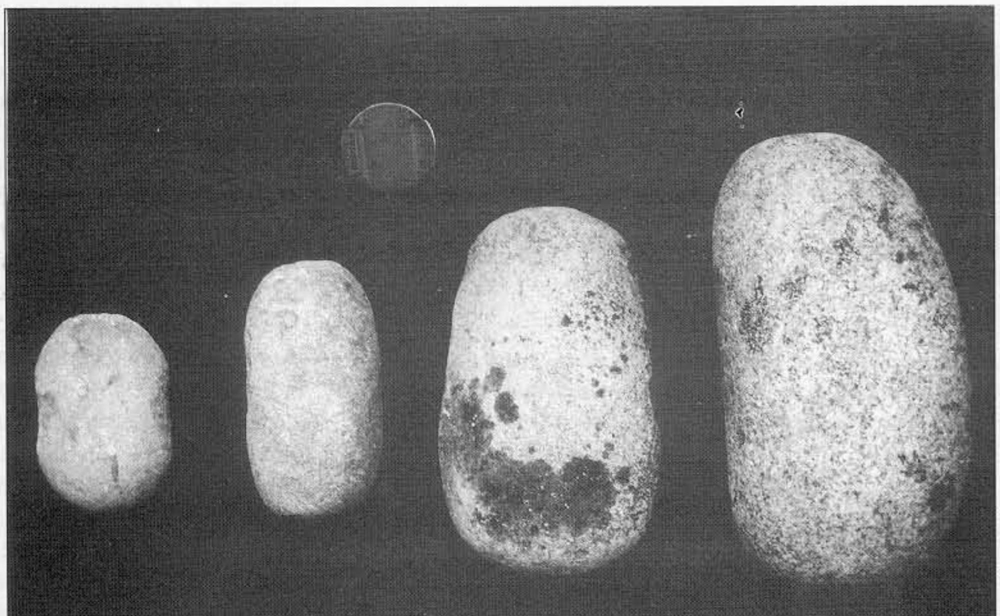

Plate 3. A selection of hammers from Cornwall now in the Zennor Wayside Museum. The example on the right has been notched for hafting.

and Blanco-Freijeiro 1981). The evidence of the hafting on the majority of the hammers can be very ephemeral, and often requires very careful examination to establish. This takes the form of notching on the edges at the middle of the stone, sometimes accompanied by slight roughening on the flat faces of the centre (Figs. 1b & 1h).

It seems likely that the hammers were originally hafted either with a strong but flexible woody material bent around the stone and bound with rawhide strips or twine with rawhide, as is the case with the surviving hammers from the pre-Columbian mine of Chuquicamata, in Chile, (Bird 1979, 105-32, Craddock 1995, 42-4, Craddock, B.R., 1990, 58 & 1994, 28-30) (Plate 2); or with thinner more flexible twisted withys, as evidenced by the discovery of such a twisted handle of hazel, unfortunately detached from its hammer, at Mt. Gabriel (O'Brien et al 1990, 30-5 and O'Brien 1994, 152), and more recently at Cwmystwyth.

Examination of the ancient hafted hammers and experimental reconstructions have enabled the often faint and rather enigmatic marks to be more fully recognised and their function understood (Craddock B.R., 1990, 58 & 1994, 28-30). In summary the notches on the edge accommodated the handle, but the pecking on the girth is more problematic. It could have been deliberate roughening of the smooth pebble surfaces to act as a friction pad to hold wedges used to tension the binding, or more probably it was damage caused where wedges were hammered in with another stone (Figs.1b, 1d, 1g).

Experimental reconstruction of stone hammers

In order to more fully understand the nature of the hammers and their distinguishing features this continuing work by the Early Mines Research Group is described here.

Three basic methods of hafting were used in the experiments. These were done either with or without some modification of the stone depending on its natural shape. The materials used were willow, hazel and ash, all as green branch or coppice wood with the bark still on, for the handles, and raw hide or hemp string for the bindings.

So far rope handles have not been used, and we have been unable to replicate the hafting suggested by the twisted withy handle from Mt. Gabriel.

In the first method, a pair of rigid wooden handles approximately 40 to 50 cm long and two to four cm in diameter were bound together and around the hammerstone with rawhide Fig. 2). Although this method has proved quite successful, it was unfortunately based on a misinterpretation of the old photographs published with the article on the Copper Man from Chuquicamata (Bird 1979, 105-32).

The second method is based on our recent examination of a newly reported hafted hammer from Chuquicamata, where the handle is made from a single piece of wood (Plate 2). In our reconstructions, using temperate European materials, a single piece of willow approximately 100 to 120 cm in length was doubled back on itself to form an open loop and secured with rawhide. The willow round the stone is protected by strips of rawhide, and the back of the stone is held in a cradle of rawhide to prevent it flying out backwards on impact.

The third method is a variant of method 2, and has proved the most satisfactory developed so far. It consists of two thin withys over a metre in length, looped round the stone and twisted together to form a handle, secured with rawhide or a string (Fig. 2). The willow around the stone is protected, and the stone cradled as in method 2.

In all three methods the binding was kept taut if necessary, by means of wooden wedges driven between the binding and the hammerstone. Where the latter was a smooth water worn cobble the surface was roughened as observed on the ancient hammers to provide a better grip. It is very difficult to predict before binding where the wedge will go and thus the roughening could be accidental damage which took place whilst the wedges were being hammered in.

Evidence for stone hammers in the south-west

Stone hammers are known from the south-west, even though they are not concentrated in large numbers at the potential mines. Some of the stone hammers in the Zennor Wayside Museum, for example, seem to have evidence of midriff notches for hafting (Plate 3) which suggests they were used to deliver a considerable blow, more appropriate to cracking rock than for grinding. However these hammers are few in number and generally lack precise provenances, much less certain association with ancient mines. Budd and Gale (1994, 14-21) collected a number of likely candidates for hafted stone hammers from the vicinity of Wheal Coates, near St. Agnes in Cornwall, but were worried by the relatively small numbers and the lack of direct association with the early workings compared to the Welsh mines.

There is another way of looking at this problem, not just why are there so few mining hammers at the potential early mines of the south-west, but rather why are there so many at some of the other British sites. Some quite small operations seem to have required enormous numbers of hammers and some of these seem to be but little used. It has been suggested that there was an element of ritual about this, donating material in the form of stone hammers to the earth in recompense for the ore removed. This however does not explain why so many of the hammers are outside the mine or in the ancient tips. An explanation is that these mines were only worked intermittently by groups who came from a distance bringing their hammers and other tools with them. Naturally they would bring an excess to cover contingencies, especially if the sources of the hammerstones lay at a distance, which is true of most of the central Welsh mines where the hammerstones were brought from the coast.

A similar situation seems to have occurred in the working of the iron meteorites found in the Canadian Arctic by the local Inuit. Each time the Inuit went to the meteorites they brought with them basalt hammers from at least 50km distance and over the years great mounds containing thousands of discarded but not necessarily broken tools built up around the meteorites. It could be argued that if the sources in the south west were being worked on a more continuous basis by groups living much closer then there would be much less need for this apparent extravagance in tools and when stone tools were too worn or broken for further mining use they could be repaired or reused on the settlements and ultimately lost over a much wider area.

There is another hypothesis. It is very possible that there may have been no need for real hard rock mining in the south-west of Britain in antiquity. The secondary tin ores could have been washed from the stream beds or from the primary deposits contained in friable decayed granite at surface, such as presently exists at Cligga Head etc. In these sorts of deposits the stone mining hammers would not have been necessary. The crumbling rock would need only a shovel and the occasional use of an antler pick or wooden wedge.

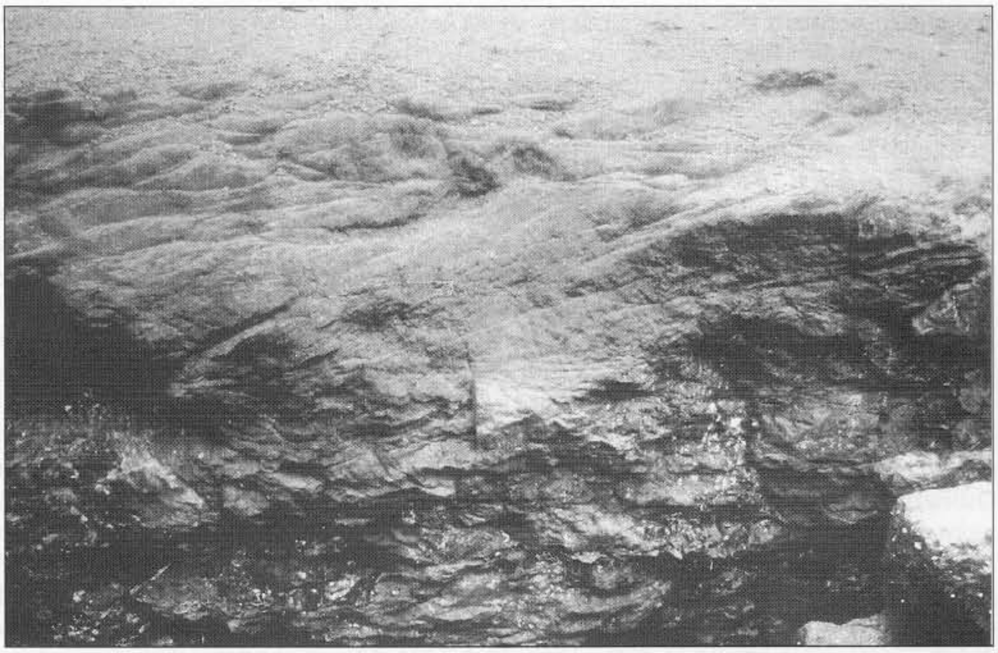

Plate 4. Remains of a shallow pit working (centre) cut by a much later trench mined with the aid of gunpowder at Engine House Lode, Alderley Edge, Cheshire. The diffuse bruising marks characteristic of battering with stone hammers.

Plate 5. Small tinwork on Challacombe Down cutting through the lynchet and thus post-dating it.

Plate 6. Small tinwork known as Scudley Beam on Challacombe Down where the lynchet apparently stops short of the cutting and has rounded edges, suggesting the tinwork pre-dates the lynchets.

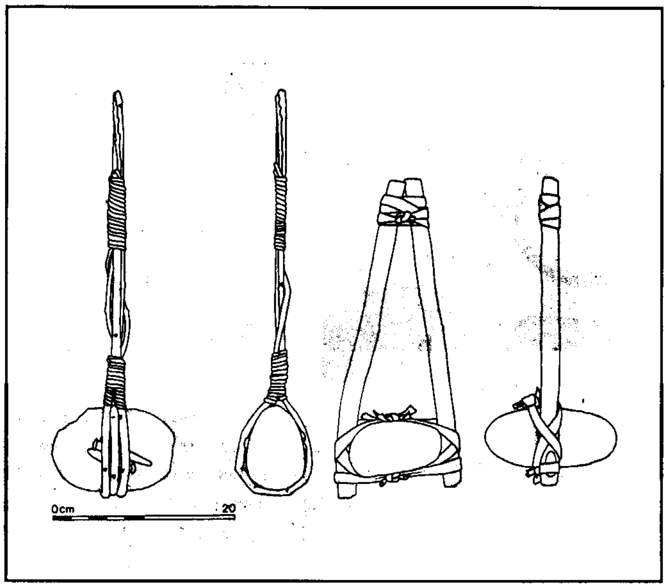

Fig. 2. Reconstruction of stone hammers used in mining experiments. That on the right has rigid handles of hazel held by rawhide, whilst that on the left has a handle of two long, thin withys, twisted together and looped around the stone and secured with rawhide or string.

The Mine Evidence

The various categories of early mine workings have recently been categorised by Cranstone (1994, 144-7). Mine workings made with stone hammers are quite distinctive, with very rounded profiles. The marks made by the stone hammers directly on the rock face are also distinctive (Plate 4), and quite different from the wedges-shaped cuts of a metal pick or the long scratches produced by a metal chisel. Gunpowder was used from the 17th century in Britain, and after blasting the rock face is left in a very jagged state, often with the remains of the shot holes every few metres.

Stone hammers were not effective against hard rock unless it had been previously weakened by firesetting (Pickin and Timberlake 1988, 165-7), and this technique seems to have been used in conjunction with the stone hammers at many of the British mines.

Fireset workings are characterised by their smooth sinuous profiles with no sharp angles or changes of direction (Craddock 1992, 145-50)(Plate 4). The shattered rock tends to peel off in plates parallel to the face, and thus few tool marks are found. In the underground workings the exposed rock faces are often blackened by soot, as exemplified by Mt. Gabriel (O'Brien 1990, 279 & 1994, 63, plate 20), and the floors of the workings are often deeply covered in layers of charcoal, ash and burnt stone. Where the fireset rock face has then been subjected to battering with stone hammers the result is again distinctive, producing shallow curving profiles of crushed rock. If the rock was quite soft such as the sandstones at Alderley Edge (Plate 4), or the dolomitised limestones of the upper levels of the Great Orme mine, such that firsetting was not necessary then the stone hammers produced a diffuse battering on the rock face. Ancient worked faces are prone to weathering, especially from frost, and pristine detail will only survive in exceptional conditions.

It is frequently claimed that more recent mining activity will have obliterated the slight evidence for prehistoric mining, but in practice destruction is rarely total. Even where the workings have been largely destroyed, such as at Parys Mountain on Anglesey, which is the classic example of a totally devastated environment, the ancient underground workings and the spoil tips still survive. The rock fragments do not appear obviously burnt, but the heaps do contain a great deal of charcoal which forms the material for radiocarbon dating. Weathering over thousands of years has disintegrated and washed away most friable materials such as any ceramic or refractory materials out of the heaps. The five mines excavated by the Early Mines Research Group, in common with other recent excavations at Alderley Edge, Great Orme's Head and Mt. Gabriel, have yet to uncover a single sherd of prehistoric pottery, only at Ross Island has pottery been recovered.

TIN AND THE STREAM DEPOSITS

The main source of tin is likely to have been cassiterite sands and pebbles from the secondary stream deposits, although at the 1992 Camborne conference on Early Mining in the South-West, Bromley pointed out that some of the near-surface primary deposits could also have been exploited. The cassiterite ores were easy to work, beneficiate and smelt. The gravels of the stream deposits were loose and could easily have been mined with just antler picks and wooden shovels creating the long irregular trenches which can be seen all over the tin mining areas of Devon and Cornwall (Bradley 1990, 29-41) (Plate 5 & 6). These were still being worked up until this century, thereby creating a very real problem of dating. The Bronze Age copper mines identified elsewhere have all been hard rock mines where the diagnostic evidence has been the surviving work face bearing the characteristic marks of working (Craddock 1986, 106-9) and the ubiquitous stone mining tools (Gale 1990, 47-8; Pickin 1990, 39-42; Timberlake 1990b, 22-9 & 1991, 179-83). By contrast the exposed gravel faces of the stream workings would rapidly weather away and there was no need for the durable stone mining hammers.

However, the trench workings are often quite substantial, and on well preserved landscapes sometimes cross other extensive field monuments such as field or land boundaries. Dartmoor is an excellent example of Crawford's 'palimpsest of the past', and the work by Fleming (1978, 97-124 and 1988) on the reeves and their stratigraphical association with other features can be applied to the stream workings. The tin workings on Challacombe Down, in Manaton parish, (Grid ref SX 693 805) lie within a few hundred metres of the well known and seemingly enigmatic Bronze Age enclosure of Grimspound. Archaeologists have long speculated on what could have attracted substantial settlement in such an inhospitable place, and why such massive fortifications were necessary - what were they defending? All previous prehistoric reports seem to ignore the nearby tin workings or at least their significance (Hansford Worth 1953, Fleming 1988, to mention just a few of the more important recent works). The industrial archaeologists consign them to the medieval period by default because there is little evidence for post-medieval or recent exploitation. However, these workings are not alone, they share the hillside with a lynchet field system, the tin workings run up the valley side and the lynchets run along the valley and thus they meet. In the recent past Challacombe Down has been covered in gorse and heather which made inspection difficult, but this has now been cleared. Some of the workings quite clearly run through the lynchets (Plate 5), but at other workings, notably Scudley Beam, the lynchet banks are rounded off and stop well short of the trench, and the mining clearly pre-dates the lynchets (Plate 6). An aerial photograph of this system also showing the relation of the lynchets to the working, was published by Greeves (1985, Plate 14), who ascribed the tin

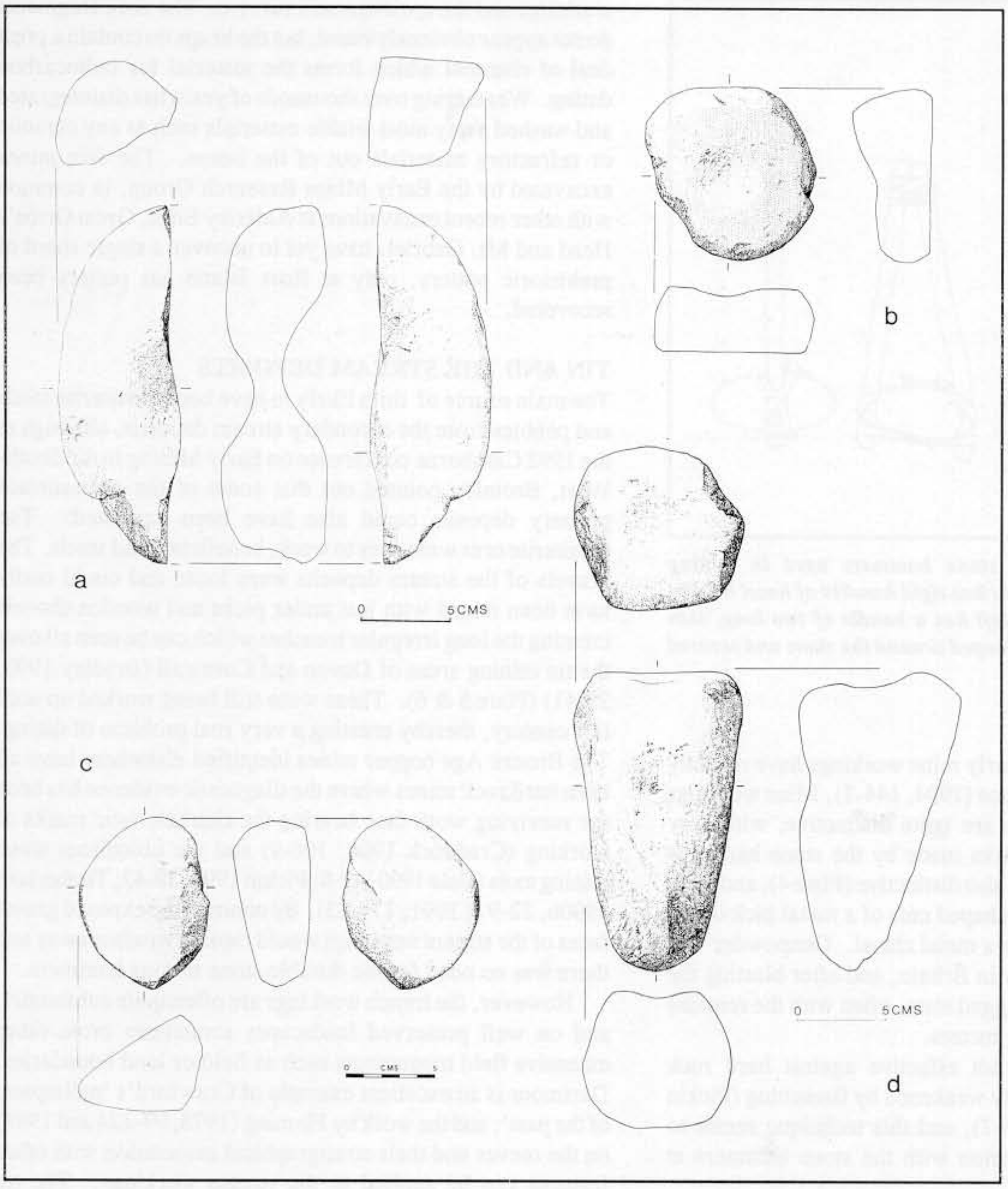

Fig. 3a. Llancyfelin. Shaped mortar used on both sides. The right hand view has a rounded profile, the left hand view has a flat surface. It seems to have been re-used as a hammer after the mortar broke in two.

Fig. 3b. Göltepe, Turkey 'Dimple Stone'. This stone has had two types of use. Both 'flat' surfaces were used as upper rubbing stones and re-used as as a small mortar, creating the dimple hollow.

Fig. 3c. Wedge shaped. Both flat surfaces have been used for grinding, probably on a saddle quern type lower stone of fine grained rock.

Fig. 3d. Göltepe, Turkey. A preshaped conical stone. There is a mortar hollow on the top end and another on the long side. The narrow pointed end may have been used as a pestle, the wear is quite slight, and could be damage resulting from driving the stone into the ground in order to use the top.

working to the 16th century or earlier and the lynchets to the 13th century. As noted above little evidence is likely to survive within the workings themselves that could give a clear indication of date (although see Penhallurick 1986 for the range of prehistoric artefacts found within old stream workings). It is also very noticeable that many of the small workings on Dartmoor are in the immediate vicinity of hut circles, the association of huts and workings is especially clear on Shapley Down, for example. Excavation of these habitation sites with a systematic sampling of the floors for detailed chemical and microscopic examination might show evidence for tin working, as suggested by Merkel at the 1992 Camborne conference on Early Mining in the South West.

Evidence of Mineral Processing

The mined ore would have been broken up, crushed and sorted to select out the copper mineral from the surrounding vein stuff, the gangue. At many early mine sites around the world there are groups of small crushing hollows in the surrounding rocks. Such small hollows are apparently not found in the British Isles, but some of the hammerstones have clearly been re-used as mortars (Fig. 1c), and separate mortar stones have been found at the mines. The large hard stone anvils with flat grinding surfaces, known as bucking stones, seem to belong to the post-medieval period in Britain, and no certain examples have been recovered from a prehistoric context. However bucking stones were used in the 3rd millennium BC, or just possibly later in the Byzantine period, at Kestel in Turkey to grind tin ore finely. It was necessary there to grind the low grade primary ore very finely in order to release the dispersed cassiterite mineral, and it is unlikely that such procedures would have been necessary in the Bronze Age workings of the south-west of Britain, but some crushing was necessary as evidenced by the crushing stones recovered from the Crift farm excavations (Buckley and Earl 1990, 69).

Rather than searching, perhaps in vain, for stone mining hammers which may not be there it would seem more appropriate to look for ore dressing or grinding stones. However whilst no sensible person continues to use a stone on a stick as a mining tool if they have access to an iron implement, stone continues in use as a crushing and grinding material to this day. It is therefore not necessarily indicative of ancient working. The nature of the tools may assist in the distinguishing of earlier from later working

The tools illustrated (Figs. 1c, 1k; 3a to 3d) are ore preparation tools from various early sites. They range from rough crushing to fine grinding. They can be distinguished from similar domestic implements by, in the case of those from Göltepe/Kestel their sheer quantity and the stone selected. The grinding of grain for example requires an open textured stone that does not clog easily, and the lower stones tend to be large. Conversely for the grinding of ore a close grained rock is more satisfactory, and a smaller surface area is adequate (This based on the unpublished experiments of R. Hard at Kestel).

EVIDENCE OF EARLY SMELTING PROCESSES

The principal field evidence for smelting is slag. In the 'traditional' ancient processes, as described in the textbooks on early metallurgy, furnaces such as those excavated at Timna in southern Israel or Rio Tinto in southern Spain, produced large amounts of slag which is virtually indestructible. However, no Bronze Age copper smelting slags are known from Britain, and this seems to be true for much of western Europe generally. There are a number of possible explanations, explained at length elsewhere (Craddock and Gale 1989, 175-92), but the most tenable hypothesis is that the primitive low temperature processes developed in Europe did not produce a durable slag in any significant quantities (Craddock and Meeks 1987, 187-204; Pollard et al 1990, 72-4 & 1991, 169-74; Craddock 1990, 69-72 & 1995, 135-44). This is likely to have been true of tin smelting as well, the small shaft furnace tin smelting experiments of Earl (1986, 17-32) produced only small amounts, and the still more primitive hearth smelting experiments (Timberlake 1994, 122-8) produced almost none at all, and both experimenters suggested such slag as was produced would have been finely crushed to release any entrapped tin prills. The very high tin content of British Bronze Age alloys coupled with the sheer quantity of bronze surviving is testimony to the large amounts of tin that must have been smelted in the south- west. Thus the few finds of tiny fragments of tin slags from the floors of some Bronze Age huts (summarised in both Pearce 1983 and Penhallurick 1986) should be taken as evidence of processes which left little durable evidence rather than small scale production. If this is indeed the case then there will be little tangible evidence to be found. However, it would clearly be wrong not to seek for traces of early smelting or to reject those that did come to light just because of a theory! It would seem most likely that at least some smelting took place in the vicinity of the mines, and thus careful examination of these areas should be carried out, looking especially for small, possibly crushed and often heterogeneous slags. Hut circles and other settlement evidence near old workings should also be prime candidates for investigation, and the sampling and analysis of the soil deposits described by Merkel at the 1992 Camborne conference seems especially important in contexts that may not yield the more tangible evidence of smelting.

From the post medieval period on, the copper and tin ores were almost always removed from the mines for smelting and thus slags near a mine are potentially significant, although another caveat is the reuse of slag as a convenient metalling material for tracks.

It is important to note, however, that the slaggy materials found near a mine need not all be directly associated with smelting the ore. Thus although the ores were not smelted at the mine in more recent times they were often roasted to reduce their bulk and weight before they were carted away, and very considerable heaps of calcine debris are found near the old mines, as for example at Parys Mountain, Anglesey where the prehistoric mine spoil lay beneath late 18th century calcine debris. Calcining was an oxidising process, and the products even when vitrified tend to be red or orange and should not be mistaken for true smelting slag. The steam engines of the Industrial Revolution produced large quantities of clinker from their boilers. This should be relatively light and gassy, but sometimes it can appear very dense, black and with a definite flow structure preserved in it. Finally there is the debris from the mine forge, every mine would have maintained a smithy where tools were repaired, and sometimes quite sophisticated ironwork was done. Our field work at the small remote mine of Nantyreira (Timberlake 1990c, 15-21) below the summit of Plynlimon, for example, revealed small broken slags which Chris Salter (*pers comm.*) identified as iron slags, presumably from the 19th century mine forge. Iron smithing slags can be very difficult to differentiate from iron smelting slags (McDonnell nd, 47-52). Similarly, iron and non-ferrous smelting slags are often identical in appearance and only chemical analysis to detect traces of the relevant non-ferrous metal would resolve whether they were the product of smelting the iron, copper or tin ores.

EVIDENCE FOR METAL PRODUCTION IN THE SOUTH-WEST OF BRITAIN

The bronze metalwork of the south-west has been studied in detail (Pearce 1983) and local types such as the Crediton palstave have been taken as indications of the exploitation of local resources. There have been attempts to identify suites of trace elements in the bronze artefacts specific to the south-west which would provide an indication that the ores of the south-west were in use (Northover in Pearce 1983, 104-7). In a later paper Northover (1987, 186-91) identifies copper with the trace content of Co > Ni as likely to have originated in the south-west). Trace element provenancing of metal artefacts is, however, fraught with problems generally, and the small scale and primitive processes of the British Bronze Age are likely to make the task even more intractable (Budd *et al* 1992, 677-86).

The problem has also been tackled by attempting to characterise the ores. Early studies on the trace element composition of the Cornish copper ores were not very successful (Edwards and Charles 1982, 1-7). This is true of such studies generally, and more recently lead isotope studies have been made on the copper and lead ores as part of a general study of the British Isles (Rohl 1995). Lead isotope studies as a means of provenancing metals have been in use now for over twenty years around the world and have produced some impressive results. The ratio between the various isotopes is much less susceptible to change during processing than the ratios between the various trace elements and thus should the lead isotope ratios should be a much more reliable indicator. However Rohl's analysis of a selection of copper ores from mines in the south-west (Pendarnes, Wheal Basset and Wheal Gorland) showed that radiogenic material in the ore deposits made the ratios very variable across even small areas of the deposit, sufficient to rule out lead isotopes as a method of discriminating these sources.

However when applied to the lead deposits of the south-west some very positive results were obtained. In the first phase of the Late Bronze Age in southern Britain, known as the Wilburton phase, dating to about 1100-1000 BC the bronzes for the first time often contained appreciable quantities of lead in the alloy. The source of the lead has long been a subject of speculation but lead isotopes of a selection of the leaded bronzes and of the deposits shows a close match with the ores from the Mendips, in the vicinity of Charterhouse.

The large trench mines at Charterhouse have always been ascribed to the Romans by default, and as Professor Todd's excavations have shown the Romans were indeed active at Charterhouse from a very early date. However the date is so early that it suggested to Todd that the Romans had taken over an existing operation, and some smelting evidence was found in a prehistoric context (Todd 1993, 59-67; this volume 47-51). The lead isotope evidence now strongly suggests that considerable activity must have been taking place from the end of the second millennium BC.

Taken all round it is probable that the evidence for early metal production in the south-west of Britain will be different from that found elsewhere. It contains the one ore field in the British Isles which escaped glaciation, and thus near surface weathered and gossanised horizons should have been more extensive. It does seem very likely that mining took place in these deposits and that evidence of this should have survived. Less than ten years ago review articles on early metallurgy could still claim there was no evidence for prehistoric mining in Britain, now over thirty mines are recognised. The evidence was there and staring us in the face all the time - maybe this will prove true for the south-west as well. The next decade should prove exciting!

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