An Archaeological Assessment of Tinworking, Mining and Smelting in England

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The Cornubian Orefield

In Great Britain, tin occurs exclusively in Devon and Cornwall within definable tin zones. In Cornwall the major zones are St Just, St Agnes, St Austell, Camborne and Redruth, Caradon (Bodmin [Fowey] Moor, Wendron, Gwinear, Gwennap and the Tamar valley. The latter is shared with Devon, whose only other tin producing district is Dartmoor. Although also present on the Isles of Scilly at Tresco, the metal does not occur in economically viable quantities.

Within the metamorphosed zones associated with the granite, polymetallic deposits are common, and can contain sulphides, oxides or carbonates of many metals. As well as copper, iron, arsenic, silver and manganese occur in viable quantities and the mining operations aimed at these minerals and their archaeology may be closely associated with that of tin. An important gangue mineral sometimes occurring alongside tin as well as copper is arsenic, which was extracted and processed commercially in the 19th and early 20th centuries.

Consumption

The main ore of tin is cassiterite, which, when smelted, is called white tin; a bright silvery metal with a comparatively low melting temperature that is resistant to corrosion. It is, however, comparatively soft and quite brittle, so it is rarely used on its own, and is more usually a constituent of alloys. Probably the earliest of these alloys was bronze, a combination of tin and copper, which has been produced since the early 2nd millennium BC.

The greatest demand for tin, from the Roman period until the late 18th century, came from the manufacture of pewter, which, in the medieval and post-medieval periods, was a combination of tin and lead, but today is made from tin with copper, antimony or bismuth. The alloy was known to the ancient Egyptians in the 2nd millennium BC (Hatcher & Barker 1974, 6) but its first appearance in Britain was in Roman times (Beagrie 1989, 170-1). Pewter was used on a massive scale for table and household wares in the medieval and post-medieval period, for which purposes it made an attractive but substantially cheaper substitute for silver. The consumption of pewter declined in the late 18th century, as good quality ceramics, tin plate and silver plate became more popular and accessible, although pewter manufacture continues on a lesser scale today (Hatcher & Barker 1974, 289).

The demand for tin from pewter was replaced by that of tinplate. Tinning of metallic objects is known in Europe from the Roman period onwards (Gibbs 1950, 392) but the manufacture of tinplates (from iron) came much later, probably in the 14th century (Minchington 1957, 1). Tinplate manufacture in Britain commenced about 1720 in South Wales (Burt 1995, 38; Jenkins 1995, 24) and the material was initially used for pots, pans and domestic uses. After the mid-19th century all other uses were dwarfed by the

demand from the canned food industry for which consumption of tin rose exponentially in the late 19th and into the 20th centuries. From 1750 the growth of the British tin industry was commensurate with that of tinplate over the next century (Burt 1995, 38). Other historic uses of tin include tin foil which represented a substantial export commodity for British tin in the late 18th and early 19th centuries (Barton 1967, 28-9). Organ pipes also contain a high proportion of tin as do various solders, which as part of the electronics industry in particular has provided one of the largest demands for tin in the later 20th and 21st centuries, but as output from the British tin industry has declined, this demand has been met by imports.

Historical research

Although many 18th- and 19th-century writers offered commentary on aspects of the history of tinworking (e.g. W Borlase 1758; Pryce 1778; Taylor 1799; Lysons 1814 & 1822; Moore 1829; De la Beche 1835; R N Worth 1875; Baring Gould 1900 & 1906) it was in the early 20th century that the topic became a major focus for historians. Lewis's *The Stannaries* (1908) was among the earliest scholarly accounts to bridge both counties, as have Hatcher's *English Tin Production and Trade Before 1550* (1973), Pennington's *Stannary Law* (1973) and Gerrard's *The Early British Tin Industry* (2000) much later. In Devon the main topical focus of historical writers has been the Stannaries including papers discussing differing aspects by Finberg (1949,155-84; 1950, 295-310), R H Worth (1910, 21-45), Greeves (1987, 145-67; 1992, 39-74; 2003, 9-29), Greeves and Newman (2011). More recently historical accounts of individual mines have been researched, e.g: Eylesbarrow (Cook *et al* 1974, 161-214; Newman 1999, 173-218), Wheal Prosper (Greeves 1975, 6-7), Steeperton (Greeves 1985, 101-207), Brimpts (Bird & Hirst 1996), often in association with archaeological surveys. As with much else in the realm of industrial archaeology in Devon, Helen Harris's seminal work *Industrial Archaeology on Dartmoor* (Harris 1966) and the complementary volume for the Tamar Valley (Booker 1968) brought historic tin mining to the attention of a wider public, followed in 1972 by Todd and Laws volume for Cornwall (Todd & Laws 1972). A general history of Devon's later mines was provided by Hamilton Jenkin's *Mines of Devon* (1974; 1981) and contemporary photographs with commentary by Greeves (1986) and Richardson (1992).

The Stannaries and earlier aspects of Cornish tin have been researched by a number of writers (Anon 1974; Buckley 1987; 1994; 2001; 2005; Trevithick Soc 1974), and general histories have been provided in Barton's *History of Tin Mining and Smelting* (1967), Earl's *Cornish Mining* (1968) and Buckley's *The Story of Mining in Cornwall* (2005). The most prolific Cornish mine historian was A K Hamilton Jenkin who produced a volume of essays, *The Cornish Miner* (1927) and fifteen district studies *The Mines and Miners of Cornwall* (1961-1969). Two *Essays in Cornish Mining History* have also been produced by Barton (1968; 1970), and other essay volumes include Brooke's *Stannary Tales* (1980) and Hall's *Mines of the Sixties* (2000). Many of Cornwall's tin mines have been the subject of targeted historical studies, including Botallack (Noall 1972); Dolcoath (Harris 1974; Buckley 2010), South Crofty (Buckley 1997), Geevor (Noal 1983), East Pool (Heffer 1985), Levant (Corin 1992), Wheal Hearle (Joseph 2004), Cape Cornwall (Joseph, 2006), Carclaze (Bristow 2008). Many of these works have provided crucial historic context to the archaeological investigations undertaken in recent years by Cornwall Historic Environment Services (CHES) and others. Publications themed around contemporary photographs of tin (and copper) mining in

Cornwall are numerous including famously Burrow & Thomas (1893), but more recently by Stanier (1998) and Bullen (2000-2008). Much relevant historical information has also been published in the *Journal of the Trevithick Society* covering a variety of usually technical themes. In addition to the material cited above, a vast array of social, cultural and folk history associated with the Cornish Mining industry and its place in Cornish identity and diaspora has been published in many forms of media though most is not specifically relevant to the archaeology.

Early history and archaeology

Evidence has been retrieved from Cornish tinworks that implies prehistoric tin extraction was occurring in the 2nd millennium BC (Penhallurick 1986, 173–224; Gerrard 1998, 14-21; Buckley 2005, 12-29). However, most of this evidence consists of artefacts, covering the period from the Bronze Age to the early-medieval period, retrieved by 19th and 20th century tinners when reworking 'ancient' tinworks. Evidence of early tin working retrieved from archaeological excavation is still rare and for ore processing and secondary metalworking is also relatively scant. However, at Goldherring courtyard house settlement (Guthrie 1969) and Killigrew Round (Cole & Nowakowski, excavated 1996 *unpubl*), which appears to have been a specialist metalworking site, significant traces of tin within slags were revealed. Various ingot finds have also been recorded including Mounts Bay, Watergate Bay, St. Erth/Relubbus and Tremough, where lumps of cassiterite associated with worked stones have been noted (A Sharpe *pers comm*). A recent find consisted of a substantial deposit of tin slag and wood charcoal found in association with possible hearth structures during a watching brief on a sewage pipeline at Botallack. The charcoal provided a radiocarbon date in the 2nd century AD, whilst analysis of the slag suggested that the tin had been mined from a local source (A Sharp *pers comm*).

Such evidence is lacking from Devon, despite the close association of the Dartmoor resource with a high level of Bronze Age settlement. Recent examination of Devon's river sediments, away from the moorland, has provided radiocarbon dates suggesting that wastes from tinworking processes were being deposited in the rivers in both the Roman and post-Roman periods (Thorndycraft *et al* 2004) but where precisely the tinworking was taking place has not been identified.

Although much inferential evidence for tinworking in the early medieval (Dark Age) period has been offered (Buckley, 2005), the first documented working of British tin is from Devon in the pipe roll of 1156 (Finberg 1949), while Cornish tin enters the record from 1195 (Buckley 2005, 32). For both counties production was then continuous until the 20th century, although the level of output followed separate trajectories, recorded by the Stannaries (*see* Lewis 1908) and consequently the character and extent of the archaeological evidence for each differs.

THE ARCHAEOLOGICAL RESOURCE

Med and Post-med tin working – shallow lode works and streamworks

Tin deposits exist in two exploitable forms. Lodes, formed through the hydrothermal process, (*see* Chapter on geology) exist as narrow veins of ore-bearing rock running through the country rock. These may extend

downwards to considerable depth, requiring deep mining techniques to access and exploit the ore. However, where outcrops were found close to the surface, they were exploited using opencast methods (openworks), or alternatively by sinking small, closely-set shafts which interconnected below ground but at no great depth and certainly no deeper than the local water table, unless the mine could be drained by adits.

Where shallow outcrops were subject to weathering in geological times they became eroded and detached to form alluvial or eluvial deposits, known as 'shoad' or stream tin.

Streamworks

Streamworks were once common in all the tin districts, but some of the best surviving field evidence lies within Bodmin Moor, Dartmoor and West Penwith, where the works occupy the valley bottoms of the majority of rivers and streams (streamworks) and numerous other low-lying folds in the terrain (dryworks exploiting eluvial deposits). There are also former lake deposits on Goss Moor and Porkellis Moor, where the whole surface has been turned over, and deep valley/estuary deposits were worked along the Hayle River, the Carnon Valley extending down into the Fal, and also near St. Austell at Pentewan. The Bovey Basin in Devon, known for its Ball Clay deposits, also once supported a number of streamworks.

Streamworks were almost certainly the earliest form of tin exploitation in South-West England, likely to have origins in the prehistoric period. However, the earliest documented streamwork in Devon, *la Drywork*, is of 1240 (Greeves 1981) and in Cornwall the first recorded examples are of the 14th century (Gerrard 2000, 61). Exploitation of stream tin resources continued well into the 19th century. The inevitable depletion of the deposits meant that lode sources would ultimately be more productive in the 18th - 20th centuries, although reworking of streamworks certainly continued during the 20th century at places such as Goss Moor, Happy Union, Restronguet and the Carnon Valley.

Streamworking methods, seen in the light of archaeological evidence and contemporary accounts, have been described by Gerrard (1987; 2000) and further refined by Sharpe (Herring *et al* 2008). Essentially the method involved separation of the tin from the gangue minerals by manual sorting and washing in water. For alluvial and eluvial workings, diversion of natural water courses was also often necessary to expose the deposits and documentary record exists of prospecting by this method. The character of the field remains varies depending on locality and specific techniques used but primarily they consist of silted water channels and/or dumps of waste material, often reflecting systematic working methods for the disposal and movement of the waste. They are usually contained within ground that has become lowered by the extractive activity, in some cases the streamworks are of great depth, demonstrating that a considerable amount of overburden and waste has been removed. Associated field evidence includes remains of artificial water courses (leats) and the earthworks of the reservoirs, which were needed to store the water used in the processes.

Lode Works

The first *in situ* tin lodes to be exploited were those that outcropped close to the surface or in cliff faces on the coast (Cornwall only) and could be worked by digging vertical shafts onto the back of the lode or by using opencast methods, variously referred to as openworks, beamworks, goffans/coffins, gunnises and gerts.

Openworks on and around Dartmoor, Bodmin Moor and within the Tamar Valley, usually referred to as 'beamworks' and typically of 16th and 17th century date (Greeves 1981), frequently have sloping sides and represent the removal of large amounts of overburden, whereas elsewhere, such as Wheal Coates, Treveddoe, and Great Wheal Fortune, workings were rock-cut from surface using a method akin to quarrying. The earliest documented openwork is of 1357 (Gerrard 2000) but by the 18th century, writers such as Borlase (1758) and Pryce (1778) refer to tinworks that were open to the sky as ancient and obsolete. However, in the 19th century massive stockworks were still being exploited at Wheal Prosper, Carclaze and Mulberry Down.

An alternative method of working the upper sections of a lode was to dig closely-spaced shafts, penetrating the ground down to the back of the lode outcrop. The term 'lodeback working' has developed in recent usage to describe this method though the tinners referred to them as shafts. Field evidence comprises conical pits arranged at close intervals, along the alignment of the lode, sometimes conjoined, with moderate turf-covered spoil heaps surrounding them on the surface. These shallow shafts are connected underground along the strike of the lode where it has been exploited. Their close spacing reflects the difficulties of undertaking waste removal and providing adequate ventilation at a time when only the minimum width necessary was being excavated along the lode. It was therefore more straightforward, given the relatively shallow depths of the workings, to create sequential, closely-spaced shafts by comparison with alternative methods available such as openworks.

The most common method of prospecting for tin lodes was the use of small exploratory pits known variously as trial pits, essay hatches, costeaning pits, prospecting pits and shoding pits. The technique was described in 1671 (Anon) and involved digging small pits, usually by a single worker, to search for detached fragments of lode, known as 'shode' (or shoad), which, depending on the concentration and the horizon of the shode within the exposed stratigraphy, would indicate the proximity of a parent lode. The field evidence comprises straight or staggered alignments or clusters of small pits with commensurately proportioned annular spoil heaps on the exterior.

Prospecting pits were also used by tin streamers to test the quality of a tin deposit ahead and to the sides of the areas they were working or were considering working. Costeaning trenches excavated at right angles to the likely strike of a lode (or lodes) were also used, though most of these are likely to be later in date. Their use continued into the 20th century, when machine-cut trenches were used for this purpose.

Dressing and smelting before *c.*1750

The dressing of tin normally took place as close to the point of extraction as possible to avoid transportation of the bulky ore, and, unique among metals in England, for much of its history tin was never smelted outside Cornwall or Devon due to the tight control of taxation by the Stannaries.

Tin dressing in earliest times was probably carried out using hand tools, very close to the tinworks but archaeological evidence for this activity is yet to be identified. Small mortar or anvil stones, suitable for hand dressing, are an occasional find (Newman 2003, 6) but all are undated and may simply indicate small-scale rather than early tin dressing or perhaps they were used for assay. By the 14th century tin was crushed and concentrated in water-powered mills. The mill buildings were constructed from stone with external wheelpits, which housed small waterwheels used to power either stamping or crazing mills. The mills were usually sited close to a natural water course from which water was diverted via leats. The earliest documented example is from 1402 at Penenkos in Cornwall where both stamping and crazing mills were present (Gerrard 2000,104) but earlier origins are likely for both of these technologies.

Diagnostic artefacts found in association with stamping mills include the cupped mortarstones onto which the stamps struck the tin and the crazing mills – rotating circular millstones between which tin was finely crushed. The former survive in abundance, particularly in Devon, where there has been a long tradition of recording them (Worth 1953; Greeves 1981). At Week Ford mills there are 13 mortars (Newman 1993); 24 were recorded at the excavations of Upper Merrivale Mill (T Greeves *pers comm*) and many other known mills have mortarstones present. A major find in Cornwall was the Retallack complex where eleven were discovered at a single site (Gerrard 1985). Crazing mill stones have survived less frequently, although examples still exist on site at Gobbet and were recorded at Vorvas, Lelant in 1907 (Penhallurick 1986, 171). At Retallack two complete examples were found along with many fragments (Gerrard 1985, 176). Mortarstones and crazing mill stones have been found on the ground within, or in the vicinity of, the mill buildings but often survive as the only evidence for tin dressing where no structure is known (e.g. at Horrabridge, west Devon). Stamping and crazing operations may also be evident through the presence of dressing residues such as tin slimes (fine particles of tin that have escaped the retrieval process) and finely comminuted gangue materials, both a product of stamping operations.

The structures of the smelting mills or 'blowing houses' were similar to that of the stamping mills but housed a furnace built from stone, some of which have survived in part within the structures at Upper and Lower Merrivale for example. The waterwheels powered the bellows of the blast furnaces and the ingots were cast into granite mould stones, many of which remain *in situ*. Slag deposits may be diagnostic of a blowing house site, even if structural remains have disappeared. Slags were often re-stamped to liberate prills of tin trapped in them; small stamping mills and dressing floors are sometimes found adjacent to blowing houses where the presence of stamped slag is also indicative of these processes.

Although a high number of early stamping, crazing and blowing mills have been recorded in Cornwall from documentation, field evidence is less numerous in that county and the greatest concentration is on Dartmoor where over 50 structures have survived and a further 30 sites are known from either artefact or documentary evidence (Newman 1998, 30).

The preferred fuel for firing a tin furnace was peat charcoal, samples of which were retrieved from excavations of a blowing house at Upper Merrivale (T Greeves *pers comm*) in the 1990s. This fuel was produced and consumed in vast quantities in both counties, although Cornwall's supply became depleted quite early (Herring *et al* 2008, 117) and from about the 15th century Cornish smelters relied on charcoal sourced from Dartmoor, which they did by Royal Charter (Fox 1994, 162). Recent research has proved that

the archaeological evidence of peat charcoal production on Dartmoor, in the form of burning sites or 'meilers' was widespread, although a method of dating the evidence is yet to be devised (Newman 2010b, 30).

Archaeology

The early landscapes of streamworking, lodeback pits and openworks

The locality and nature of all these primarily surface techniques and their associated remains varies, but generally field evidence is widespread in the granite areas where tin was produced, surviving particularly well on open moorland such as Bodmin Moor, Kit Hill and Dartmoor but also, lode workings in particular, have been recorded on smaller isolated patches of ground in West Penwith – at Lanyon and Morvah Hill – and much of upland West Penwith, especially at Greenburrow (Ding Dong), Trewellard Hill near Geevor and Sancreed Beacon. There are also coastal locations such as the Cot Valley – Wheal Hermon and Ballowal and Botallack. The latter class of working may well be amongst the earliest lodes to be exploited, given their visibility, ready accessibility and self-draining potential. Tinworks often also survive and have been recorded within woodland, such as Steeple Wood near St. Ives, Prideaux Wood and the Luxulyan Valley nearby, Kings Wood in the Pentewan Valley and Gunnislake Clitters. Generally speaking the moorland and coastal evidence in Cornwall is better than that contained with the woodlands. There are extensive and well-preserved beamworks and pit workings in the heavily wooded Tamar and Tavy valleys in West Devon and East Cornwall. Devon examples recorded by Waterhouse (*unpubl*) include the spectacular and complicated shode and outcrop workings on three lodes in Morwelldown Plantation, known to have been in existence and old by the early 18th century; mixed pitting and beamworks in Luscombedown Plantation and Hatch Wood, on the same lodes as the huge Gunnislake stockwork (Cornwall), first recorded in 1467; the deep gunnis with multiple shaft-like holes in its roof at Frementor in Blanchdown Wood; and the recent discovery of huge beamworks on the line of the Devon Great Consols Main Lode in Greenaven Wood, later worked for copper, but first recorded as Willys & Boynabeame tinworks in 1579 (R Waterhouse *pers comm*).

Field survey and aerial photographic transcription have so far dominated the archaeological recording and analysis of tin streamworks, surface lode works and all associated earthworks, including water courses and reservoirs. A fair selection of Cornish tinworks have been recorded using large-scale earthwork survey techniques (i.e. hachured plans) including streamworks at West Moor, Minzies Down and Harrowbridge (Gerrard 1987; 1994; 2000) and a variety of tinwork types at Colliford (Austin *et al* 1989), Kit Hill (Herring & Thomas 1990) and Bodmin Moor (Herring *et al* 2008). Similar work in Devon includes surveys of streamworks at Greena Ball and Mistor (DTRG 1996; 2003; Newman 1998); Lydford Woods, Stanlake and Hartor Brook (Gerrard 2000); Beckamoor Combe (Newman 2011; DTRG *unpubl*), Crownhill Down (Wilkinson 2010) and lodeback pits at Roos Tor (DTRG unpub). Within the Tamar Valley an ongoing recording project by Robert Waterhouse to map and record medieval and post-medieval surface and underground tin & copper mining of the Tamar Valley is as yet unpublished.

A good source of landscape information regarding openworks and some streamworks is the OS 1st and 2nd edition 25-inch maps where many were accurately depicted but modern archaeological surveys have also

been undertaken at Colliford (Gerrard 2000) and by English Heritage at a number of Devon locations including Hexworthy, Holne Chase and Vitifer (Newman 1996; 2002; 2006; 2006a). A large number of Level 2 surveys and reports of Dartmoor tinworks reside within the NMR and the DNPA GIS system, while many Cornish tinworks have entered the HER through the National Mapping Programme (NMP).

In Cornwall and parts of west Devon, data concerning most aspects of field evidence for tin working have been entered into the GIS, set up to serve the World Heritage Inscription of Cornish Mining. This includes areas previously surveyed in detail such as Kit Hill (Herring & Thomas 1990), the Minions Survey (Sharpe 1993), the St Just Survey (Sharpe 1992). The GIS includes whole-county summaries of industrial activity from the OS 1st edition 25" mapping, and maps of individual shafts, and incorporates data from the National Mapping Programme (NMP): it is a comprehensive research tool.

Archaeological excavations of early tinworks are few. Streamworks were excavated in advance of the Okehampton bypass rescue project (EH *unpubl*) and as a precursor to the construction of Colliford Reservoir (Gerrard 1983; Austin *et al* 1989). A research excavation was carried out on streamworks at Lydford Woods in 1994-5 (Gerrard 1997). A lodeback working at Rosedale Mine has been excavated by Sharpe (Sharpe 1996) but remains as the only example. Work on a similar site at Indian Queens in advance of A30 improvements had to be abandoned when the fills began to subside (Sharpe *pers comm*). Tin openworks are yet to be explored through archaeological intervention, although a small exploratory trench was attempted at Colliford (Austin *et al* 1989, 62-6).

Tin mills have a longer pedigree of archaeological study than most aspects of tin working and were of interest to 19th century writers such as Kelly (1886) and Burnard (1887-90). In the 20th century fieldwork and survey has been carried out by Worth (1953), Greeves (1981), Gerrard (1985; 1986; 1989), Newman (1993), Herring (2008). However, modern excavation is limited to the stamping mill at Colliford (Austin *et al* 1989), the blowing mill at Upper Merrivale (Greeves *see interim reports*) and a possible early smelting site at Brownie Cross in Devon (S Taylor CHES, *forthcoming*).

The collection of slag samples is a useful method of identifying the locations of blowing houses, where no other remains survive and slag analysis has helped with a variety of research questions, including developments in smelting technology (Mallam *et al* 2002). Trace element analysis is now being used to relate prehistoric bronze artefacts to areas of particular orefields (A Sharpe *pers comm*).

The Later period 1700-1900

Mines

The origins and early development of deeper, fully underground tin mining are not yet completely understood. However, the techniques probably represent a progression from the early practices used in lodeback workings, whereby the problems inherent in working at greater depth, including flooding, were overcome by technological innovations. These included the driving of adits and the installation of pumps to drain the mines. A section of a wooden pump column from Hermon Mine, West Penwith has produced a mid 16th century C14 date, which implies that pumping techniques to drain lower levels of this mine, which began life as an open cliff working, were developed at least by that date (Reference ###).

Mechanized hauling, explosives, water power and later, steam power all enabled the working of tin mines to greater depth. The need for capital to develop extensive underground mines as well as organizational and social changes to the industry are other factors in the adoption of deep underground mining and were key to its progress. The chronological and some technological issues associated with these developments have been considered at historical and archaeological level by numerous writers, including Hatcher (1973), Greeves (1981), (Burt 1995) Gerrard (2000), Buckley (2006), Herring *et al* (2008), Newman (2010). Certainly by the time of Carew (1602), in the early 17th century, mining underground was the mainstream method of working for tin in Cornwall and by the 18th century, along with the copper mines, tin mines were expanding on a massive scale. By that time Devon's more marginal tin lodes were being worked on a much smaller scale by comparison although the working of stream deposits lingered on in parts of Devon and were still of importance well into the 17th century, a few still worked in the 19th.

Tin mines often expanded to form large complex landscapes, both at surface and underground, incorporating the many processes involved. Also, tin mines frequently worked copper deposits and occasionally wolfram, either in tandem with or separately to the tin. Some writers have suggested (i.e. Buckley 2005) that the deep mining methods developed in Cornwall for copper, particularly pumping, were an enabling factor in the further exploitation of deep tin deposits which had formerly been inaccessible, and that tin mining owed much of its later prosperity to these developments.

The techniques of later tin mining have provided a wide array of archaeological and structural remains at surface but much below-ground evidence certainly survives also. Recording and survey of the former is well advanced but the latter has barely begun, although many unpublished underground surveys have been undertaken by caving enthusiasts, such as Plymouth Caving Club, as a means of mapping underground remains (A Neill *in lit* 24-Mar-2011), and the St Just Mines Research Group who have been developing new underground recording techniques.

The archaeological record for the extractive components of tin mining at surface incorporates the remains of the shafts and adits and all that may have been associated with supporting the underground activity. This includes the shafts themselves, which although usually capped, are sometimes evident by the presence of waste (deads) raised up the shafts and dumped at surface in often very large heaps. Associated surface evidence includes that of the hauling, pumping and transportation systems, which all have characteristic field remains. Although many adits are blocked at surface, many others are still open and continue to provide underground access and drainage. They too may have substantial spoil heaps leading away from the portal and evidence of tramways for the movement of ore and waste.

Unwatering of tin mines was being undertaken using machines by at least the 17th century and by the early 18th, the evidence for pumping in moderately deep mines includes water-power technology, such as waterwheels, for bucket lift, flop-jack and rag and chain pumps. Subterranean water wheels are also known to have existed, and there is a possibility that some evidence of them may survive. Polberro at St. Agnes has an underground chamber which was almost certainly for a water wheel (A Sharpe *pers comm*) and a similar example has recently been recorded at Marquise tin and copper Mine in the Tamar Valley (R Waterhouse *pers comm*). Flat-rod systems and associated balance bob pits etc, used to transmit power to shaft pumps from remote surface water wheels, were developed in the later 18th century. Field evidence of

these systems is widespread but the unique example at Eylesbarrow where upright stone supports for the rods survive intermittently for over 1.1km (Newman 1999, 124).

Hauling was achieved in shallow and undeveloped mines using the windlass and horse whim, but for deeper mines, water-powered hoisting devices were also developed. These often have characteristic field evidence of smaller rectangular pits, which accommodated the winding drum, adjacent to the main wheelpit.

Steam engines, for both pumping and hoisting, were introduced in the 18th century and continued to be the foremost source of power for these tasks well into the early 20th century, particularly in Cornwall. They were superseded in the 1920's by electric power as the Grid developed, or as sites were able to produce their own power using generators. The stone-built engine houses that once contained the steam engines and their boilers and chimneys are the main material evidence of pumping and hauling, many surviving as intact building shells, collapsed ruins or stumps. A small number survive with their machinery intact, such as at Robinson's Shaft, South Crofty and Levant. The technological developments and variants of steam engines have been well studied historically (Barton 1969; Brown *et al* 2005) and Adam Sharpe's reports on the Mineral Tramways Engine House Project (Sharpe *et al* 1991) has provided a useful study of their development and diversity. Various surveys have also supplied a body of field data (Sharpe 1986a-c; Pye Nance 1996, 109-22). The significance of steam engine houses to the narrative of 'Cornish Mining' has been thoroughly discussed in the standard literature.

Ore Dressing

Tin dressing floors may comprise combinations of a large variety of portable and fixed installations but all essentially fall into the categories of crushing, calcining, classifying and concentrating. Of these processes, some have left more permanent evidence than others.

For the 18th, 19th and part of the 20th century, developed forms of the medieval stamping mills continued in use as the main method for crushing the ore. Most were powered by waterwheels with batteries of stamps mounted either side, though after 1800 larger batteries stamps were frequently powered by steam engines. Always associated with stamping mills were the settling pits and buddles within which the crushed tin was separated from the gangue and concentrated as well as tailings pits for cleaning the water used and slime recovery, which were often quite massive. The substantial amount of water required was supplied via networks of leats and often contained within very large artificial reservoirs. Dressing floors were covered by timber-framed sheds with either thatched or planked roofs or later, galvanized sheeting was used, though these rarely survive at all but the most recently abandoned mines, usually due to conservation efforts such as at Geevor and Tolgus.

These sites consist usually of an artificially leveled area containing the wheelpit, dressing floors and other structures as well as portable installations that have left no visible evidence. Both rectangular and various forms of round (i.e. later) buddle commonly survive as sunken structures or earthworks as do other forms of tin retrieval system such as Linkenback tables. Early (i.e. late18th-early 19th century) stamping mills have survived less frequently in Cornwall, often having being destroyed by later activities although

examples are known at West Penwith, in Rose Valley and Botallack Bottoms and the Cot Valley, also various sites in Zennor. A particularly fine surviving example is to be seen at Porthmoina, with clear structural evidence (Herring 1996). Seven survive at Eylesbarrow in Devon, dating from the early 1800s (Newman 1999, 138), and at many other locations in that district with other good early 19th-century survivors at Keaglesborough (Newman 2011, 206). Later variants, powered either by large waterwheels or steam engines with massive stamp batteries and multiple ranges of round buddles, are more common in Cornwall in all of the tin districts, at West Bassett (Palmer & Neaverson 1987; 1989) for example or Phoenix, Levant, King Edward and others.

A major source of archaeological information is contained within the residues of tin dressing which lie downstream of the dressing mills. These deposits also often contained sufficient residual tin to make re-working them economically viable, such as the extensive workings at Trevellas Combe and near the harbour at St Agnes. The greatest concentration were in the Red River Valley, tailings works being found almost continuously from the south of Camborne to the sea at Gwithian. Sadly little earthwork or structural evidence of these now survives.

Calcining of tin ore was achieved in the 17th to 19th centuries in reverberatory calciners or burning houses. Tin kilns were first recorded in 1671 (Anon) but no archaeological evidence from that period has been retrieved, all the surviving examples being of 19th or early 20th century date. Later burning houses were often robust, reinforced stone-built structures and many have survived, including intact examples at Atlas Mine in Devon (Richardson 1992, 63), and Hardhead on Bodmin Moor (Herring *et al* 2008, 76). Other examples are known including at West Beam and Tavy Consols in Devon and Wheal Call (St. Just), Wheal Coates, Wheal Ellen and Tywarnhayle Mine (St. Agnes), Rose Valley, Morvah, and others. A later, 19th-century innovation was the Brunton calciner, which contained a water-powered rotating calcining floor. Several survive in Devon, i.e. Gawton, South-Devon Consols, Owlacombe, Wheal Friendship and in Cornwall complete examples survile at Tolgus and Geevor, with shells at Levant, South Hewas, Botallack, Poldice, Basset Stamps, West Basset Stamps.

One of the gangue minerals that resides alongside tin and copper was arsenopyrite or mispickel, known in the Westcountry as 'mundic', which contains arsenic. Apart from the need to clean tin and copper ores of their arsenical content, calcination was also used as a means of concentrating arsenic as a marketable bi-product, when collected from the inside of the calciner flues. In the late 19th and early 20th centuries, large calciners specifically constructed as arsenic works, with labyrinth flues and associated chimney stacks, became a major feature of the surface activity, particularly in the Callington and Tavistock areas but also in west Cornwall at Levant, Botallack and others. The calciners, labyrinth and stack at Levant have been the subject of a detailed survey in advance of recent consolidation works undertaken there (Sharpe 1994).

Of all the industrial processes associated with tin mining in the 18th to 20th centuries, smelting is among the least studied by archaeologists. Major smelting works existed within that period at about 30 locations in Cornwall and the history behind them has been considered in some detail (Barton 1967, 94). In Devon a handful of very small smelters are known after 1700, though by the 19th century the few that survived were concentrated around Tavistock and the Tamar Valley (Greeves 1996, 84-9). Reverberatory furnaces were introduced for smelting tin in the early 18th century. These furnaces used coal instead of charcoal, the

charge of tin was no longer mixed with (and contaminated by) the fuel and the need for bellows powered by a waterwheel was dispensed with as the ore was reduced by the application of heat alone. By the 19th century, most tin smelting was conducted in reverberatory furnaces, although some blowing houses remained until the mid century. Smelting was an operation carried out independently of the mines and tin smelters within the region were initially concentrated close to the Stannary Towns and navigable rivers or harbours. In Cornwall smelting activities migrated from east to west as production shifted from tin-streaming to deep lode mining. Many important tin smelters were concentrated in Penzance, Hayle, Truro and the St Austell area but Redruth also developed into an important centre for tin smelting along with the Tamar valley on a lesser scale.

Movement of materials and waste at surface and in the vicinity of the mines was most commonly via tramways, extending from within adits and near the shaft heads, bringing the stuff out of the mines, to various destinations, including spoil heaps, mills and dressing floors. They often survive as very subtle linear earthworks. Very occasionally iron rails remain in place. In hilly country such as Dartmoor and Bodmin Moor and the Tamar Valley, inclines are a common feature, connecting hilltop ore sources to dressing floors located in valleys (*see* Barton 1964). At Carclaze a canal system was deployed to move materials, including underground sections, constructed in the early 18th century (Bristow 2010, 40-1).

Transport systems associated with the mining industry on a broader scale (and therefore including copper, lead and other minerals) includes some major railways, plateways and tramways. There is good survival of some early rail systems such as the Poldice Plateway and the Redruth and Chasewater Railway, Luxulyan Valley Railway, Liskeard and Caradon Railway. Some have been subject to archaeological assessment (Gossip 2000; Sharpe 2006; 2007).

The tin industry also played an important role in the development of seaports around the coast and estuaries of Cornwall and south-west Devon. On the River Tamar alone, Calstock Quay, New Quay and Morwellham were all serving for the transport of tin copper and other minerals, and the Tavistock to Morwellham Canal with its associated incline, subject to a recent in-depth study (Waterhouse *forthcoming*), certainly carried tin. Cornish ports including Hayle, Portreath and Devoran all of which have been the subject of studies (Cayhill 2000; 2002a; 2002b) and evidence of many transport systems associated with Cornwall's mineral past have been recorded in GIS layers from early map information, including some from the 18th century.

Within Cornwall, the metal mining industry was a fundamental driver in the development of many other aspects of the human landscape. From small settlements to large towns like Camborne and Redruth, the location of communities, the type of housing, facilities, places of worship, transport systems and in many other spheres, the influence of mining is firmly embedded in the infrastructure and character of the modern county. This effect is less obvious in Devon, though visible in places such as Tavistock and Mary Tavy. Following recent debates concerning the scope of Industrial Archaeology and the need for the discipline to embrace the social aspects of the industrial period as well as the technology (Gwyn & Palmer 2005), it is quite important for archaeologists to consider these topics in any overview of tin mining's material past, particularly when undertaking landscape studies. A start has been made on this through

the Cornwall Industrial Settlements Initiative (CISI), and studies of Hayle, St. Just, Redruth, Camborne, Tuckingmill, Hensbarrow have been completed (Cayhill 2002c-f; 2004).

The Archaeology of Tin Mines

In Cornwall and in Devon to a lesser extent, the deep mining of tin was commonly associated with that of copper, and the material differences at surface are often only notable among the evidence of the dressing processes. Underground activity and associated support installations at surface differed little. Surface remains of large tin/copper mines tend to represent extended periods of operation, whereby earlier features have often become effaced, buried, leveled or altered by later operations, frequently culminating in part or total demolition of structures and leveling of spoil and other features after the demise of mining activity. Survival at individual mines is often only partial.

The contribution of archaeology to the study of later tin mining is restricted mainly to the recording of surface installations using standard investigation and survey techniques, such as earthwork survey, building survey, rapid assessment and aerial survey. The contribution of documentation should not be overlooked either, which for tin mines may sometimes be very extensive, and include flow sheets, technical specifications, technical drawings, underground and surface plans, photographs, costs, analyses of efficiency, etc all of which contribute to interpretation of archaeological sites and landscapes.

The County Council in Cornwall was somewhat ahead of many other local authorities in England in appreciating the cultural value of its mining heritage assets and the task of compiling a detailed basic record of the county's mining remains is well advanced, thanks in part to the effort put in for the successful WHS bid. But also for many years prior to that event, recording by the Cornwall Archaeological Unit (CAU, now the Cornwall Historic Environment Service or CHES) enabled a substantial body of fieldwork to be built up. Large recording projects at Kit Hill (Herring & Thomas 1990), Minions (Sharpe 1993), Bodmin Moor (Herring *et al* 2008), St Just (Sharpe 1992) are all detailed landscape studies, containing large-scale surveys and encompassing documentary and cartographic data. But the unit has also been responsible for a great many smaller, targeted recording projects, assessments and watching briefs in mitigation of development and in advance of conservation projects and this is reflected in the county HER. (The total output of mine related reports by CHES is immense and too large to list or discuss in detail in this document. However, a selection of examples is cited above and it is hoped that a bibliography will be available with the final publication of the Framework).

Field recording of Devon's later mines includes Level 2 surveys by English Heritage, accessible through the NMR and a number of larger-scale earthwork surveys by individuals. These include Wheal Cumpston (Greeves 1978), Steeperton Tor Mine (Greeves 1985), Wheal Prosper (DTRG *unpubl*), Wheal Fortune (DTRG 1993), Eylesbarrow (Newman 1999), Brimpts (Bird and Hirst 1996) and grey reports for Hooten Wheals, Caroline Wheal Prosper and Holne Chase (Newman 1996; 2004; 2006a).

Conclusion

The tin industry in Cornwall and Devon, is one of the most studied mining topics by historians and has received attention from archaeologists, especially those engaged professionally, on a scale not yet achieved by other non-ferrous metals or any extractive industry in any region of England. It is notable however, that the most substantive general historical accounts of tin mining are of the 1960s and 70s, and are usually biased towards Cornwall. A revised historical narrative which encompasses both Cornwall and the substantial documentary legacy of Devonshire, and places less emphasis on Cornish identity, is long overdue. Hopefully it would include much information gleaned from archaeological research, which for tin mining has come a long way since Barton's dismissive statement that a 'square yard of documents' will 'reveal far more of substance than a square mile of old ruins' (Barton 1968, 10). However, although over the past 25 years a massive quantity of high quality field recording has taken place, more recently this work is being directed at specific conservation, planning or management issues. While this work continues contributing to the accumulation of data on certain topics, many broader research themes remain unexplored. Future research should try and address this imbalance. In Cornwall in particular, a realization that metal mining is one of the crucial element of the historic landscape in the county has enabled a great deal of attention to be leveled at it. But outside the field of independent and amateur researchers, an enthusiasm for tin mining as a subject with broader research goals is restricted to a relatively small number of practitioners and academics.

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