6 Clay

Peter Claughton

6.1 Introduction

Clay is one of the most common minerals worked in England; there is no county which does not have some form of historic clay workings within its boundaries. Although this section is tasked with examining post-Roman clay working, it should be noted that it is one of the earliest extractive industries, with evidence of clay being used from the late Mesolithic/early Neolithic period onwards. However, there has been little detailed archaeological investigation at extraction sites, probably because they were, on the whole, confined to small pits, easily overlooked compared with the associated ceramics production sites.

The working of clays is, perhaps, the most complex of the extractive industries in England. Whilst all clays have a common geological source, the manner of their deposition and the form they take, the methods by which they were worked and the archaeological features which resulted from their working, are diverse. Those workings range from ephemeral shallow pits in the Holocene river clays of East Anglia, to the vast china and ball clay operations associated with the granite of Devon and Cornwall; they also include the sprawling brickworks of Bedfordshire and the specialist fireclay workings of the Coal Measures on either side of England's central spine, extending from the Midlands to the Scottish border.

Clay extraction gets but scant mention in the regional research frameworks. For the southwest of England, the ball and china clays, by virtue of the scale of operations and their landscape impact, are mentioned, but only attract two bibliographic references (Webster 2008, 235). For Northwest, England, McNeill and Newman (2006,184) acknowledge the working of local clays, but only regret the lack of archaeological investigation of the brick kilns, not the places where clay was extracted. Slightly more emphasis is placed on the sources of raw materials in Northeast England for the Neolithic Period onwards (Petts 2006, 30, 79 & 98) with reference to the possible identification of clay pits. The greatest emphasis is given to the use of clay in pottery and brick making, as for the East Midlands (Cooper 2005, 250-51), with the excavation of kilns taking precedence. In his paper on the Industrialisation of the Staffordshire Potteries, David Barker (2004) acknowledges the increased importance of imported raw materials and the transport infrastructure that made those imports possible, but provides no detail as to the origins of the clays, be they local or imported.

As has happened with other extractive industries, such as ironstone and iron ores, the focus in the past has primarily been on the final process of firing the clays in brickworks and pottery kilns, rather than the extraction of the clay itself; the brickworks and kiln sites are prominent structural features in the landscape, whereas extraction sites may be less so and less attractive as a focus for research. Much of the early evidence for clay extraction has been lost, with only minimal recording as methods have expanded in scale; although that is changing in some sectors, notably the china clay areas of Southwest England. What survives might be buried under later development or erased from memory through time.

6.2 Geology[1]

The principal components of all clays are hydrated aluminium silicates formed by the decomposition of feldspathic rocks, i.e. granite.

Clays are found either in their primary position, in the granite, or as secondary deposits resulting from their erosion, movement and re-deposition by water and/or glacial action. Secondary deposits of varying geological age are the principal sources of clay in England and their characteristics are largely determined by the secondary components they contain. China clays, or kaolins, are primary deposits and, as such, are lacking in plasticity. Ball clays are secondary deposits with minimal secondary components, particularly low in iron and therefore white-firing, with good plasticity resulting from the fine particle size distribution, plus the presence of other minerals such as illite and smectite. Organic compounds also have an effect on the makeup of the clay.

Other secondary clays, such as red and earthenware clays, contain relatively high iron and other components, which give greater plasticity and a lower firing temperature, but result in red or yellow colour after firing. Marl or calcareous clays are also secondary deposits, with high proportions of sand and lime. They are generally lacking in plasticity as are the sandy or siliceous clays found in the middle reaches of river systems. Clays are frequently found as hard, compressed geological strata in the form of mudstones or shales.

Secondary clay deposits have been laid down at different geological periods and under varying conditions, giving rise to a range of characteristics which make them suitable for particular uses. The principal of these are listed below by the geological date of their deposition, from the oldest through to the most recent. However, clay working is not confined to the geological strata or locations as listed; small isolated clay deposits of any geological age may have been exploited for brief, or sometimes extended, periods without attracting geological, historical or archaeological attention.

Palaeozoic

Silurian – clay from several horizons in the Wenlock Shales in Shropshire has been used as a substitute for fuller's earth, locally referred to as 'Walker's Earth'.

Devonian – hard shale found in Devon and Cornwall, and adopted for brick making in the 19th and 20th centuries.

Carboniferous – Coal Measures clay deposits of varying characteristics found stratified with coal and other minerals, e.g. ironstone. In the north of England commercially exploitable fireclay is the seatearth for some of the coal seams, such as the Halifax Hard Bed. These have been used for a variety of purposes, including sanitary ware, pipes and brick making, with the fireclays being of particular importance for the production of refractory bricks for furnace lining from the post-medieval period onwards. Some cream-firing clays are found, and have attracted interest for specialist products from at least the Roman period. The Etruria and Ruabon marls are also a very important source, and were the original materials exploited in the Staffordshire Potteries.

Mesozoic

Triassic – reddish brown mudstone (Keuper Marl) found in a belt running from Northeast England, through the Midland counties to Southwest England. Exploited for brick making and terracotta ware from the 17th century onwards.

Jurassic – Lias clays in the limestone belt from Lincolnshire to Dorset were used for pottery, terracotta and brick making from at least the Roman period. Deposits of fuller's earth (montmorillonite) in the Great Oolite series near Bath, which has been used for various purposes, including pharmaceuticals and engineering. Oxford clays, with a high carbon content, are found to the southeast of the limestone belt and were exploited for brick making (Fletton bricks) around Peterborough and across Bedfordshire from the late 19th century onwards (Fig 6.5). Kimmeridge clays were used for brick making in what is now South Oxfordshire.

Cretaceous – the Wealden clay in Kent, Sussex and Surrey, and a small outcrop near Swanage in Dorset, has been used for brick making from the 18th century onwards. Lower Greensand clays were quarried for use as fuller's earth in Surrey and Bedfordshire. Gault clay, found between the Upper and Lower Greensands, and used to produce light coloured bricks, particularly in Cambridgeshire, in the 18th century. The same clay is also found in a wide band across the Surrey-Hampshire border and was used for pottery in the Roman and medieval periods. Gault clay from around Aylesford in North Kent was transported to London in the 17th and 18th centuries for the production of English 'delftware'.

Tertiary

Eocene – clay from the Reading Beds found in Essex, Berkshire through to Kent and around the Hampshire Basin; it was used for late medieval white wares and later, in the 17th century, for brick making. London Clay from Essex, London and Berkshire was extracted for brick making from the late 17th century onwards. A series of clay deposits, of variable characteristics and uses, is the Barton, Bracklesham and Bagshot Beds of the Hampshire Basin and to the west of London. These include the ball clay of the Wareham Basin, Purbeck in Dorset, used as a source of white-firing clay from the 17th century onwards (see below).

Eocene/Oligocene – white-firing ball clays of the Bovey and the smaller Petrockstow basins of Devon (see below). Fremington Clay in North Devon and the brown-firing Watcombe clays used in the Torbay area of South Devon.

Quaternary

Lower Pleistocene – the Icenian clays in the eastern parts of Norfolk and Suffolk used for red brick production in the 19th century.

Middle and Upper Pleistocene – the boulder clay found

across the north of England is of variable quality, but there has been widespread small scale exploitation for brick making. 'Clay with flints' of the same geological ages, found capping the chalk scarp from Bedfordshire and Berkshire through to North Kent was used for brick making in the 19th century.

Holocene – alluvial clays found in the lower reaches of large river systems across England and used for tile and brick production from the Roman and medieval periods onwards.

6.2.1 The geology and chemistry of fireclays

Fossil soils, palaeosols, occur as the 'seatearths' of coal seams. An example is fireclay, a commercially valuable mudstone, which may be used in the production of refractory bricks and crucibles, and without which many metallurgical and specialist processes such as glassmaking would not be possible. Fireclay, as mined, is a hard, rock-like, material. It consists principally of kaolinite, hydrous mica (illite), and quartz in various amounts (Waters et al. 1996, 39). The proportions of these constituents, the grain size, and the presence of minor constituents (such as iron minerals and alkali metal oxides) determines the final ceramic properties of the fired brick. Undesirable minor constituents could act as fluxes and lower the vitrification temperature of the clay. Fireclay is not the only refractory substance originating from the Coal Measures. Ganister is another, being an almost pure silica deriving from a sandy palaeosol.

Fireclay can be modelled as a system containing two mutually insoluble components, silica (SiO_2) and alumina (Al_2O_3). At high temperatures, a silica polymorph, cristobalite, and a new mineral called mullite ($3Al_2O_3$-$2SiO_2$) form (Callister 2002, 409). The solidus of the silica-alumina system, within the normal composition range of natural fireclay, is 1587 ± 10°C. This temperature is only just above the melting point of iron at 1538°C. The position of the eutectic (Callister 2002, Fig 12.27) implies that to remain at least partially solid in a blast furnace, working temperature firebricks should contain less than 7%, or significantly more than 25%, alumina. In the 19th century these two types of refractory or firebricks were made from ganister and fireclay respectively.

6.2.2 China and ball clays in Southwest England

In the UK, china clay is a term used for the primary deposits composed mainly of the mineral kaolinite, produced by alteration of granite *in situ* on certain parts of the upland moors in Devon and Cornwall, notably Southwest Dartmoor, Bodmin Moor and around St Austell.

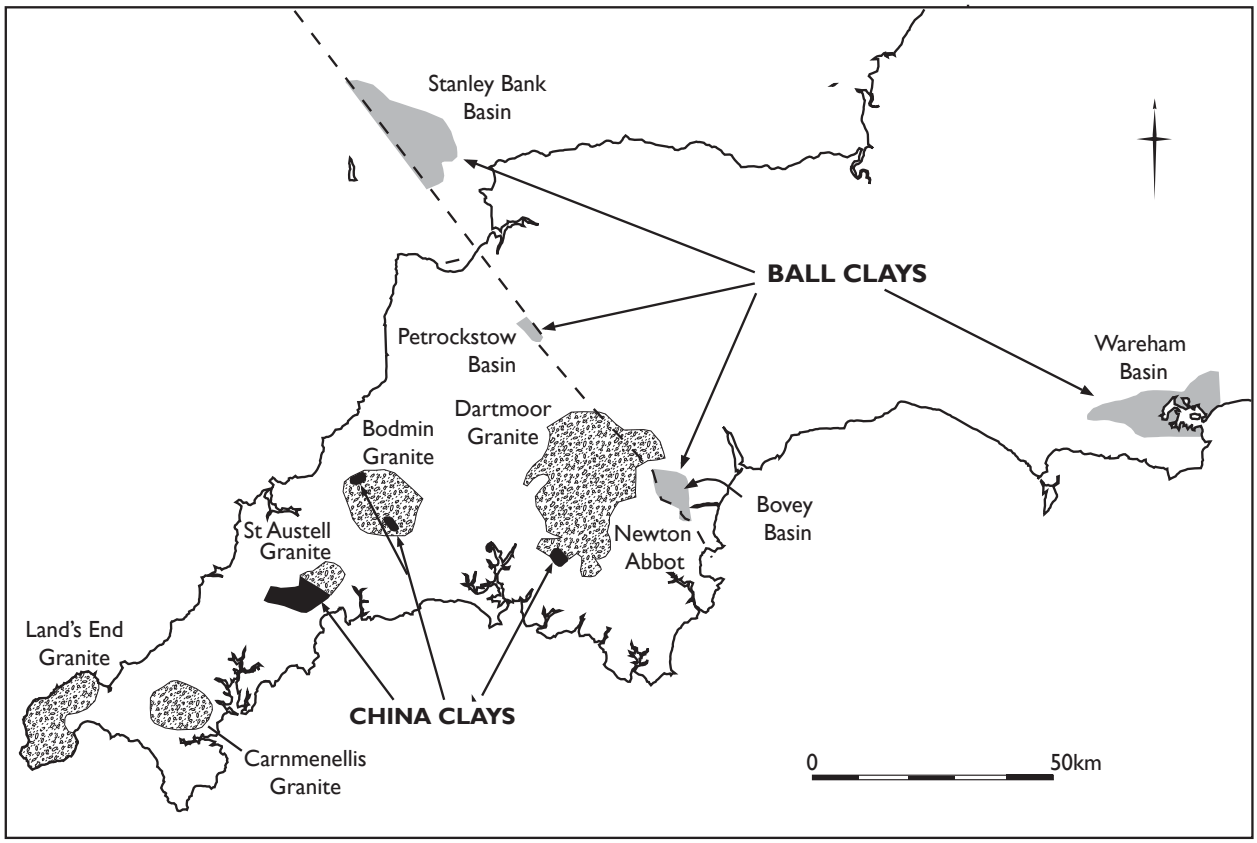

Figure 6.1 Ball and china clay deposits in Southwest England. After C M Bristow et al.

Figure 6.2 General view of Goonvean china clay works, St Stephen in Brannel, Cornwall. © Historic England

Ball clay is a secondary deposit derived from relatively recent (Eocene and Oligocene) erosion of both primary kaolinite deposits and sedimentary rocks, and found in basins lying to the east and northeast of the granite uplands (see Fig 6.1 - the Stanley Bank Basin is a submarine deposit with no historic exploitation).

Decomposition of low iron granites on the uplands from Dartmoor westwards to the far west of Cornwall, has left significant deposits of kaolinite mixed with mica and quartz, through a combination of hydrothermal action and weathering. Once separated from the coarser elements (mica, quartz and any partially decomposed granite) the fine kaolinite or china clay provided a white-firing component for use in the manufacture of fine porcelain although, from the late 19th century, that only accounted for 10% of use; the majority (80%) being used as a paper filler. China clay has in itself relatively poor plasticity and has to be used with ground china stone (below) and/or other clays. In addition to its use in the manufacture of ceramics, it has, in recent years, found a range of uses including as filler and a coating in paper manufacture. Partially decomposed granite, known as china stone and found in association with the kaolinite deposits, is, after grinding, used as a component in the manufacture of porcelain, along with the kaolinite. Economically viable china clay deposits are restricted in their location, generally funnel shaped deposits they are of limited extent on some of the granite uplands, with the largest deposits being in an arc on the high ground to the north of St Austell in mid-Cornwall.

The Dorset ball clay deposits are the largest in area, but the shallowest in depth. Here, the Eocene Bagshot Beds contain three clay members which occur over a wide area. However, it is in the Wareham Basin where most of the ball clay working has been located. The southern edge of the deposits is the upturned chalk, which forms an east-west escarpment through Corfe Castle. Against this southern edge, the ball clay lenses are also upturned, contorted, faulted and thrust, while further north the clay lenses level out. Like the Petrockstow Basin, there is more illitic mica present than in the clays of the Bovey Basin, which improves its plasticity, but alters the firing properties. The technical properties for use in the ceramic industry are the governing factor in the market value of the ball clays.

In the Petrockstow Basin of North Devon, the sedimentation was controlled by fault movements associated with the northwest to southeast trending Sticklepath Fault System. Faulting divides the basin axially into a deep central trough around 670m deep, with flanking shelf areas to the northeast and at the south end. Fluviatile sedimentation (sands and gravels) took place in the axial trough areas, with some silty clays representing occasional overbank deposits. Later, the north-west flowing river transgressed beyond the central trough area, and overbank deposits, particularly in the shelf areas, became more prevalent. The sediments in the trough are mainly cyclical with upward transitional sequences from sandy gravels to smooth clays. Cyclicity is also evident in the shelf deposits, without the gravels, but containing areas of carbonaceous clay and lignitic material. The shelf deposits are thought to be Oligocene in age. The clay mineralogy shows disordered kaolinite, illitic mica and traces of montmorillonite, derived from the weathering of the Culm Measure country rocks. Faulting, folding and unconformities make quarry development complicated.

On the basis of a gravity survey, the Bovey Basin in South Devon is the deepest with an estimated depth of 1300m, the later sediments probably being of Oligocene age. The Basin can be divided into two

geographical units, with the larger northern area being the more important. This forms a rough parallelogram stretching northwest from Newton Abbot to beyond Bovey Tracey, a distance of 11km and maximum width of 8km. The southern area from Decoy to Aller contains Aller Gravels and Greensand as well as the clays. The clay mineralogy is complex, ranging from well-ordered kaolinite with little micaceous mineral, to moderate disorder and higher mica content. The source of the clay mineral was thought to be Dartmoor, and that is probably true for the 'china clay' like clays of the Chudleigh Knighton Member, showing derivation from the northwest. However, there are elements present from both weathered sedimentary rocks and granitic sources. Despite various unconformities, most of the other more disordered kaolinitic clays show derivation from the south and where that clay mineral came from is matter for conjecture. The upshot is that the extraction zones in the southern area have been mainly confined to the eastern outcrop and the southern western outcrop. The remainder of the Basin is sandy sequences with largely sideritic clays of no commercial value.

6.3 Historical and archaeological context

6.3.1 Production in the medieval period

The use of clay for the manufacture of pottery dates back to the late Mesolithic to early Neolithic period in England, with gabbroic clay from St Keverne on the Lizard peninsula in Cornwall providing a good example for a distinctive source, identifiable across a wide geographical area from the early Neolithic to the Romano-British period (Quinnell 1987). Clay was also being used in the production of bricks and tiles, for both flooring and roofing. By the Roman period, clay had also been introduced as a building material in its own right, and was being used, unfired, in the construction of walling. Brick and tile manufacture was on such scale during the Roman occupation of England that centres of production have been identified and investigated, along with the extraction pits that were the source of the clay, as at Minety in Wiltshire (Millett 1992 177). Following the departure of the Roman administration, the demand for fired clay products was much reduced. Brick and tile manufacture appears to have ceased completely, and there were long aceramic periods with little or no pottery production.

Figure 6.3 Ball clay being cut by 'spaders' in a Bovey Basin clay pit during the 1950s. Note the varied stratigraphy of the deposits. © BCHS

Once there was renewed demand for construction materials, bricks, like stone, were easily robbed from the surviving remnants of the Roman infrastructure. There is some evidence to imply that brick making may have re-commenced in the early medieval period, with the suggestion that the Roman-style bricks used in the building of the Saxon church at Brixworth, Northamptonshire, were of contemporary manufacture (Drury 1981, 126). There is though, some doubt about their origins (*see* Eaton 2000, 129). By the mid-12th century, there is clear evidence for renewed brick and wall tile production, first at Coggeshall Abbey in Essex and, later in the century, at a number of as yet unidentified centres across Southeast England. During the same period, there was renewed production of roofing tiles at Southampton and as far north as the Yorkshire coast near Scarborough, all of which would have drawn on local clay sources (Drury 1981, 127). English brick and tile production was, however, in competition with products imported from the near continent. There is also documentary evidence for continental, Flemish, involvement in English brick making from at least the 14th century and an increasing number of references to the erection of brick kilns in association with particular building projects.

Flooring tiles, primarily used in ecclesiastical buildings, were being manufactured at a small number of centres in England during the 10th and 11th centuries. Following a break, with no evidence for production, tile making using a variety of decorative styles resumed in the 13th century. Limited centres of production for some of those styles are implicit in their limited distribution across southern England but, as yet, they have not been identified (Drury 1981, 129-30).

With increasing demand for bricks and tiles in the late medieval period, the latter being used for both flooring and roofing, there is both documentary and archaeological evidence for production on a number of sites across southern and eastern England. Drury (1981, 136-38) cites the investigation of sites at Danbury in Essex, Lyveden in Northamptonshire and at Boston in Lincolnshire, but they were confined to the

kilns and associated structures and did not embrace the extraction sites. Clays were, however, evidently readily available to the extent that temporary kilns would be erected alongside large construction sites, drawing on local supplies of raw material and fuel (almost exclusively wood). By the end of the period, brick and tiles were in common use across a wide swathe of the country from the southwest to the northwest of England and along the borders with Wales, but less so in the upland areas where stone was more readily available.

In the East Midlands, the production of pottery is in evidence for from the 10th century onwards, utilising the estuarine clays of the region, with certain localities, for example Stamford ware, having the qualities to make them desirable over a wide area (Stafford 1985, 58-60). Much the same can be said for other parts of England, with production increasing throughout the medieval period, and certain localities taking precedence. Some of those localities were to continue in production well into the post-medieval period and have been the subject of detailed investigation (for example Davey & Walker 2009), but again, few address the subject of clay extraction in any detail.

Some unprocessed clays were used from the medieval period onwards. This was not confined to their use in construction, as with 'cob' walling in Devon and other parts of Southwest England: where suitable strata were found, such as the Lower Greensand across southern England, 'fuller's earth' would be extracted and used for its absorbent qualities to remove oil and grease, such as lanolin, in the treatment of woollen textiles.

6.3.2 Post-medieval production

Beyond the end of the medieval period, there were certain leading factors in clay production, and amongst these were the new uses for clay products. Advances in the metallurgical industries, along with developments towards the end of the period in the use of steam to generate power, created an increased demand for refractory brick and the exploitation of the fireclays found in the Coal Measures. Although in the 18th century blast furnaces were built of stone throughout, the more advanced types had a separate refractory lining (Tylecote 2002, 132). The lining was at first refractory sandstone, but later, brick was used. In 1718 Abraham Darby I used Stourbridge firebricks in blast furnaces at Coalbrookdale (Gurcke 1987, 19). As early as the 16th century, Stourbridge fireclay crucibles were being used by glassmakers (Gurcke 1987, 19). The completed firebricks could make very long journeys and are often marked with the maker's name, helping archaeologists trying to date furnaces and identify the sources of materials. Firebricks from Stourbridge, Newcastle and Scotland have been found as far away as Pacific North America (Gurcke 1987).

New uses, such as the introduction of tobacco pipes, stimulated the demand for white-firing clays: a factor which encouraged a rapid increase in clay production from North Devon in the mid-17th century (Grant 1983). The 17th century was also a period of expansion for pottery production, which resulted in Staffordshire becoming a centre for mass production in the following century. This was marked by the need to import clays from a much wider area, drawing on supplies from as far as Devon and Dorset.

6.3.3 Clay production after 1750

The expansion in industrial production and its associated settlements, brought a vast increase in the demand for bricks, tiles and, by the mid-19th century, the pipes and fittings required for improved sanitation. Large brickworks and sanitary-ware producers were set up adjacent to suitable clay sources and close to the intended markets. Clay Cross, in Derbyshire, is a good example of the latter (*see also* Harris 2003 for a small scale example in Lancashire) and the vast brickworks of Bedfordshire exemplify the former. The clays rich in organic material, found around Fletton near Peterborough, were particularly important. Those clays could be fired without drying and their organic content was found to contribute to firing, reducing fuel costs by two thirds (Brunskill 2009, 18). In many localities across southern, and parts of eastern and northwestern England, brick making expanded to satisfy local demand, exploiting local resources loosely defined as 'brickearth' (technically unbedded wind-blown loess soils, but frequently also used to describe alluvial clay deposits)(*see* Fig 6.4). Typical of these would be the development of brick-making in the area around Burnham-on-Sea, north of Bridgwater in Somerset (*see* Murless 2000 for a gazetteer of brick and tile manufacturers in that area). The mechanical properties of the bricks produced across the country, related to the clay used, and would vary depending on their end use: facing brick for the outer skin on walls; common brick, used for backing facing brick or for internal walls; engineering, very hard, dense bricks as, for example those produced at Accrington under the trade name NORI.

In Shropshire, from the earliest times, glacial clays were dug from small open quarries wherever they existed. Their use decreased as large industrial projects developed requiring a more durable supply of bricks, but they have continued to be used as an additive to other clays to get the right mix.

Figure 6.4 Distribution of Loess in England & Wales, after Catt (1988) - typically less than a metre in depth (stippled) but some deposits (black) might be over one metre.

The red clays have been worked mainly in the east Shropshire Coalfield particularly around Broseley and Hadley. They are highly suitable for brick and tile manufacture, and the trade name 'Broseley' became synonymous with being the best, protected by a local association of about a dozen manufacturers. Unusually, the clay has been mined underground as well as from outcrops by quarrying. Underground mining consisted of using adits and shafts, and workings on the pillar and stall system. Most of the mines were very small and used crude equipment. In order to keep costs to a minimum, donkeys were often used underground for haulage, a distinctive feature of Shropshire mining. The peak of underground mining seems to have been reached in the 1890s when some seventeen underground workings were contributing to a total county production of nearly 50,000 tons a year. With the development of larger quarries, the total county production increased to about 130,000 tons in the 1930s, at which time there were about eight underground mines. Underground working ceased soon after the Second World War but quarrying production rose to over 150,000 tons in the 1950s, and 267,000 in the 1980s. A few mines have produced both red and white clays for example, Blists Hill.

The white clays have consisted mainly of fireclays from beneath the coal seams, often worked in conjunction with them. The poorest seams of clay have been used for domestic pottery tobacco pipes, and when mixed with other clays, sanitary ware and

Figure 6.5 Oxford Clay extraction at the Pillinge Brickworks, Beds 1930. © Britain from above EPW033897

drainage pipes. The purer clays were used for the manufacture of fire bricks and furnace linings. Mining was by shafts and adits but the underground working consisted of both pillar and stall and long wall methods. The white clay mines tended to be more mechanised than red clay workings because their product usually demanded a better price. The peak period for underground working appears to have been about 1905, when about ten white clay mines were at work; about half were also producing coal. Production from these mines often exceeded 20,000 tons per year. The last underground mine in Shropshire closed in 1964 (Brown 1966). The production of white clays increased tremendously in the 20th century rising to 400,000 tons following the widespread introduction of large-scale opencast working. Shropshire's production fell back to about 150,000 tons in the 1980s but was still about one fifth of total English production. Many of the opencast sites were principally for coal, and sometimes the clay had to be lifted and stocked or it would have been lost.

Shales from the local coal and ironstone mines have also been used extensively in brickworks adjacent to the waste tips. The waste from ironstone picking produced flat topped tips, which were re-worked by hand or by simple excavators, the material was then transported in tubs on narrow gauge rail, hauled by chain to the brickworks.

Innovative techniques in pottery production were developed as new materials became available. The discovery of large deposits of china clay in Cornwall stimulated porcelain manufacture, first in Plymouth and then in Bristol (Smith 1992, 3). Demand increased rapidly after the china clay deposits attracted the attention of the Staffordshire potteries, and production became centred in the West Midlands. By the second part of the 20th century, there was considerable diversification in the use of china clay outside the ceramics industry. The extraction of ball clay in Southwest England (Devon and Dorset) also benefitted from the expansion of pottery and other ceramic production after 1750. Whilst there was some local use, increasing quantities were shipped to the West Midlands and to potteries in western continental Europe (BCHS 2003, 9-16).

Ball clay also provided the basis for the early terracotta industry in the London area but, in the later part of the 19th century the industry migrated to the coalfields of England and Wales. Perry and Thurlow (2010) have provided an exhaustive study of the history of ball clay, china clay and associated deposits in Southwest England, and Stratton (1986) provides a useful overview of the development of terracotta, its clay sources and the expansion which attended its migration to the coalfields.

Refractory brick production also expanded to meet industrial demand, using new materials such as 'ganister' rock, crushed and mixed with a small amount of fireclay to form a clay suitable for moulding. Crushed shale and, in some cases, slate were also used to supplement natural plastic clays in a range of brick and other constructional ceramics. In the 20th century fireclay, the Stannington Pot Clay, along with two other clay seams, was worked underground in the Loxley Valley to the west of Sheffield and, by the 1960s, there were still three companies working a total of five mines. The Ughill Mine, operated by J Wragg & Son, was a drift working with one vertical shaft for ventilation and another in the course of sinking. Compressed air drill and blasting were employed in working the top 4ft 6in of the clay seam, using a pillar and stall system with the pillars being worked on retreat as each section was abandoned. Clay was hand-trammed to a central station for haulage to surface. Production in 1964 was 290 tons per week (Brown 1964). These were perhaps typical of fireclay extraction operations on either side of the Pennines.

Increasingly, clay was also used for cement production from the late 19th century onwards. In 1824, Portland cement was patented in England by Joseph Austin, who used an impure form of limestone with a high clay content, known as a 'cementstone'. Today it is made by calcining a mixture of limestone and argillaceous material, i.e. shale or clay (Manning 1995), and most cement plants are situated where limestone and shale (or clay) occur close to one another.

6.4 Processing

Prior to 1750, most, if not all, clay extraction was from surface deposits dug by hand. The exception may have been the working of Coal Measure fireclay deposits, which could have been extracted from deep workings alongside the coal. With expanding production, post 1750, came deeper working, mechanisation and the

development of new techniques in both working and processing the clay.

The extraction of clay and shale for brick and tile making remained a largely surface operation, expanding in scale with increased mechanisation. Hand, horse-drawn and locomotive operated, temporary tramway systems were a feature of all large-scale clay working from the latter part of the 19th century. However, from the first years of the 20th century, there was increasing mechanisation of the extraction process itself, using large rail-based, steam-powered excavators, many of which were adaptations of standard machines used in rail and canal construction. The machinery surplus at the completion of the Manchester Ship Canal provided the first examples of their acquisition by the clay industry, including steam shovels and multi-bucket excavators (Huxley 2002, 2-3).

It was not until 1926 that machines were specifically constructed for the industry, when an electric-powered shale planer of North American design was built for use in the Peterborough clay pits (Huxley 2002, 11). Shale planers continued to be used up to the end of the 20th century. Walking draglines were introduced after the Second World War for the removal of overburden, before which steam (later electric-powered) shovels were used; both being used in conjunction with transport booms to transfer unwanted material to worked-out areas of the clay pits.

Draglines and shovels of increasing size were also used for clay extraction. On the larger sites, these supplied moveable crushing and mixing plant, which fed tramways and, later, conveyor belts for the transport of the clay to brickworks. From the late 1940s, greater use was made of crawler and pneumatic tyred internal combustion powered vehicles, stimulated to a large extent, by the availability or wartime surplus equipment. This process of mechanisation is well illustrated by the publications of Bill Huxley (2002; 2006).[2]

Deep working of fireclays developed in parallel with that for coal, although in many cases, particularly along the outcrop of the Coal Measures east of the Pennines, fireclay working was the primary objective. The principal technological innovations were, however, in the processing of the clay and the development of improved kilns. From the early 19th century onwards, there was increased mechanisation in crushing and mixing of both clay and shale. The development of continuous firing in the Hoffman kiln, made for significant fuel savings, as did the introduction of the tunnel kiln into England late in the 19th century. There was, however, a continuing preference for the beehive, down-draught kiln for the manufacture of firebricks, as the intense heat required could not be developed in Hoffmann-type continuous kilns.

In the extraction of specialist clays, ball clay and china clay, there were a number of working methods not used elsewhere. Ball clay extraction, once it had proceeded beyond shallow open surface trenching, required distinctive techniques for deeper working. The first stage was to sink pits on the outcrop of the clay seams. These, known as 'square pits', were timber lined and braced, the optimum size being 18 by 24ft (5.5 x 7.2m) - established by trial and error. The pits were dug to a depth of 50ft (15m), with a series of hand pumping 'lifts' and ladders. About 12ft (3.6m) of solid ground was left unworked between adjacent pits and the waste from one pit was dumped in the abandoned pit. A wooden crane of a type unique to the ball clay industry called a 'crab', comprising a pivoting 'gallows' held in place by two legs called 'tie backs', would be erected alongside the square pit to hoist the clay and waste to the surface in an elm bucket.

By the 1870s shaft mining had been developed to reach the deeper 'potters' clays, whilst the lower value 'stoneware clays' continued to be worked in open and square pits where there was minimal overburden. Shafts were generally about 13ft by 6ft (3.9m x 1 .8m), fully timbered in particular fashion and divided into two compartments, one for hoisting by means of a crab and one for access and the pump lines. After sinking to the desired seam and creating a sump, two side drives were made in opposite directions along the strike for about 100ft (30m), supported by closely set, green, round larch timbers. The seam would then be worked in a 'fan' shape. The life of the shaft was rarely more than 2-3 years and, on completion, the timbers were often withdrawn for re-use; the worked out areas soon collapsed under pressure from the surrounding clay (Tony Vincent *pers comm*). In North Devon, these shafts were steeply inclined, at about 15° from vertical, and fitted with tram rails to allow the wagons used underground to be hauled to surface. The shafts were worked using simple timber head-frames (BCHS 2003, 27).

Drift working using inclined 'adits', although common from at least the 18th century in other clay working areas, was introduced into ball clay mining in the 1930s; two parallel tunnels were used in Devon and single tunnels in Dorset, driven down the dip of the clay seams. Tramways were laid in the tunnels which were secured with timber and, later, steel roof supports. By the 1970s, in North Devon, and a little later elsewhere, underground work was abandoned, and the ball clay was worked opencast on a large scale, taking advantage of motorised heavy machinery to strip off the overburden and access the clay (BCHS 2003, 32-35).

Prior to the recent introduction of large scale, mechanised, opencast operations the actual extraction

Figure 6.6 Mica drags at the Hemerdon china clay works, Devon in 2012. The site has since been completely destroyed by the advance of clay working. © Phil Newman

of clay, be it in shallow open pits or underground, was by hand. Special tools were used to cut and handle the clay, the action of which created the 'balls' giving the clay its common name. Only in the mid-20th century was there limited mechanisation, with the introduction of hand-held pneumatic spades.

One distinctive feature of the surface installations used in connection with both shaft and open pit working was the 'high back'. This was a wooden ramp structure, on which rail mounted wagons were hauled up, and discharged at the upper end onto a stockpile of that particular clay seam. Each type of clay had to have its own high back so there was no indiscriminate mixing of clay seams. In the mid-20th century, these high backs were largely replaced by the use of dumper trucks (Tony Vincent *pers comm*). In the 1950s, the Newton Abbot Clay Co. used Blondins for lifting clay from the bottom of one of their deep pits in the Bovey Basin (BCHS 2003, 31), and these were also used in the Cornish china-stone pits.

All the features connected with ball clay working are ephemeral. Timbering and steel roof supports were stripped out for re-use as workings were abandoned. What was left underground was slowly crushed by movement of ground. Apparently, it is not unusual to cut into the timbering of long abandoned 'square shafts' during modern opencast working, but the workings themselves have little integrity because of ground movement. The surface features, such as the temporary head-frames, were removed and re-used in new shaft sinking, tramways were re-located at the same time and much of what might have survived when underground work was abandoned has not been recorded beyond that afforded by historic photography.

Once the overburden and those upper parts of the deposit which were discoloured by iron staining had been removed, the china clay was worked by means of shallow pits. The clay was broken up in a stream of water, which carried away the kaolinised material leaving behind the waste sand. On a hillside working, the water could run naturally to the settling area or 'strake', or be drained from the pit by means of a vertical shaft at the base of the pit draining into an adit. Waste sand was shovelled manually in stages, 'shammelled', out of the pit, later using tramway inclines. Water was essential to the extraction of china clay, and extensive leat systems were required to ensure supplies, particularly after the introduction of high pressure hydraulic monitors to break up the kaolinised ground. As pits were worked ever deeper, it was necessary to pump the kaolin rich water to surface; this eventually required steam powered pumps. Disposing of the vast amounts of waste sand was

problematic. Using wheelbarrows and tramways to tip the waste around the working pit could sterilise large areas of ground, which might later be worked for the china clay it contained. From the latter half of the 19th century, the amount of land required for waste disposal was minimised by hauling it up tramway inclines to tip it on to conical tips, 'sky tips', which were to become prominent landscape features marking out the china clay working areas of Cornwall and West Devon.

Once the kaolin rich water (slurry)had been removed from the workings, any remaining waste sand and mica had to be removed by passing the water through a series of 'catch pits', later replaced by an improved method using a series of long channels referred to as 'mica drags', before the kaolin was allowed to settle out in large shallow pits. The drags were often remote from the clay pits, and long ceramic pipelines were installed to transport the slurry, often over several kilometres. The clay then had to be dried. At first, in some cases up until the 1920s, this was carried out by cutting the settled clay into blocks, and allowing it to dry naturally in large open-sided sheds. This could take up to eight months and, from the mid-19th century, was replaced by artificial drying in coal fired 'pan kilns'.

China stone, the partially altered granite found in association with china clay, was quarried in conventional fashion before being crushed and ground to a fine powder in water-powered 'stone mills'. The mills have a distinctive layout with the grinding pans being driven by a central water-wheel. Brickworks were often opened up adjacent to china clay workings, to make use of the low grade clay; these facilities could also supply the bricks required to build and maintain the pan kilns (Smith 1992).

6.5 Infrastructure

6.5.1 Transport

Up to the middle of the post-medieval period, the extraction of clay was, on the whole, supplying a local demand. Bricks, tiles and pottery might travel some distance from where they were produced, but the clay was normally found locally and made no great demands on the transport infrastructure of the period. From the beginning of the 17th century and onwards, there was increasing demand for clays with special qualities, which justified their being shipped considerable distances to the manufacturers; an example is the ball clays from Devon and Dorset, used for tobacco pipes. Clay deposits found close to the coast had a real advantage, as coastal shipping was by far the cheapest form of bulk transport. At Bideford in North Devon, storage facilities, known as clay cellars, were built close to the quay to serve the coastal shipping trade and, when canals were eventually built to serve the clay producers in the Bovey Basin, clay cellars were erected alongside them (Grant 1983, 39; BCHS 2003, 43) (Fig 6.8). By the second half of the 18th century, with large scale pottery manufacture developing in Staffordshire, a means of bulk inland transport was becoming essential. The development of Britain's canal network was driven by the need to move bulk cargoes such as clay at a relatively low cost. The Staffordshire and Worcestershire Canal, opened in 1771, provided North Staffordshire's potteries with an essential link to the River Severn, and a route for ball and china clays coming in from Southwest England. Canals were used to a limited extent in the clay producing areas in Cornwall and Devon. An early canal, partially underground, served the Carclaze Tin Pit, north of St Austell in Cornwall, and this was later utilised to serve subsequent china clay operations, but there is no evidence it was used to transport the clay in barges (Bristow 2011). Three short canals served the ball clay workings in Devon, the Rolle Canal in the north, and the Stover and Hackney canals in the Bovey Basin (Pye 1991). Some clay may have also been shipped via the Bude Canal, as Grant (1983, 39) notes the existence of 'clay cellars' on the line of the canal.

Temporary tramways provided essential transport

Figure 6.7 A fully laden train of clay carts exits the adit at a Dorset ball clay mine. © BCHS

Figure 6.8 The buttressed wall of a ball clay cellar at Teignbridge in Devon. © BCHS

Figure 6.9 Surviving aerial ropeway from 1924 at Claughton Manor brickworks, Lancashire. © Peter Claughton

within many clay workings and, in their later years, most had access to mainline rail services. Blondins have been mentioned above in connection with the haulage of clay from the working pits. Aerial ropeways also had a role to play in the movement of clay from the pits to the processing sites. One ropeway was in operation until quite recently at the Claughton Manor Brickworks in Lunedale, Lancashire (Fig 6.9).

From an early date, horse-drawn tramways were of some service to the china-clay workings around Hensbarrow, St Austell in Cornwall, taking clay down to the coastal ports. After the arrival of the mainline railway in the late 1850s, these were eventually superseded by standard gauge branch lines serving the whole of the St Austell district. Some china clay processing then migrated to sites adjacent to the railway and the large port at Par, with clay slurry being fed by pipeline to those sites direct from the pits. The Bodmin Moor china clay pits were not as well served by the railways, with only the one branch line serving the western part of the moor, and producers had to rely on long pipelines to bring clay down to their processing sites (Smith 1992 14-15).

China clay producers on Dartmoor, in Devon, had the Lee Moor and the Redlake tramways in addition to the mainline railway running to the south and west of the moor and some producers relied on long pipelines to the mainline (Hall 1981; Wade 1982). The ball clay workings in the Bovey Basin of South Devon were eventually served by a standard gauge branch line in 1867, but before that date relied on the Stover and Hackney canals (BCHS 2003 43-44). In North Devon, a light railway was constructed in the 1880s to link the ball clay workings to Bideford (Messenger 2007). The Dorset workings were served by a tramway as early as 1805-06 (BCHS 2003 46), which continued to work until 1907. Other horse-drawn tramways were built at Ridge in 1840 and Goathorn in 1854. The latter was replaced by a light railway with access to the mainline in 1907, but once the clay workings it served were exhausted, the same railway took clay from other sources directly to the quay for coastal shipment (John Rowley pers comm)(*see* Roberts 2012 for a description of the surviving tramway features in Dorset). The expansion of clay working in the Midlands and in the coalfields was also associated with the introduction of the mainline railway network, frequently fed by locomotive-powered tramways, as brickworks and other clay consumers exploited sources further from their processing sites. Both tramways and standard gauge railways had an important role in feeding coast and river ports involved in the transport of clay, as was the case in parts of Lincolnshire (e.g. Plant 1968). After the Second World War, an increased reliance on road transport gave greater flexibility but led to the inexorable reduction in the use of tramways and the mainline railway across the whole range of clay working.

6.5.2 Settlement

From the mid-18th century onwards, there was an increase in the demand for clay-based products. Frequently, this demand led to the exploitation of new sources of raw materials on a large scale. In an industry which relied heavily on manual labour, more housing was needed at or near the locations of these sources.

The presence of brickworks and, by implication, the associated extraction processes within historic townscapes, might be recognised. However, little reference has been made to their impact on the settlement pattern - see for example the work on the Historic Town Assessment for Bletchley and Fenny Stratford in Buckinghamshire (English Heritage 2010). Stewartby, to the south of Bedford, was a model village erected in the late 1920s to provide housing for workers on the adjoining brickworks and the associated clay pits (Huxley 2002, 19). In a similar manner, to the south of Peterborough, the rise of the Fletton brick industry would have had a significant impact on the expansion in housing development but this does not appear to have attracted any archaeological investigation.

However, in some areas the impact of industry on settlement, has been recognised, although as in the Ironbridge area of Shropshire, clay extraction might only be one amongst many industries (Alfrey & Clark 1993). In Cornwall, the Industrial Settlement Initiative has sought to identify the relationship between clay extraction and settlement, highlighting the distinctive village structures on and around the china clay area to the north of St Austell (Cahill Partnership & Cornwall HES 2005a, b & c). Similar relationships should be apparent in other clay working areas.

6.6 Archaeology

From the data supplied from the Historic Environment Record (HER) across England (NAMHO 2011), it was already evident, that the majority of the archaeological investigation carried out for clay extraction was focused on Devon and Cornwall. This fact is reinforced by the results of searches for data not included in the various HERs.

The ephemeral nature of small-scale clay extraction, and the manner in which it is encountered in the course of general and unrelated archaeological investigation, is illustrated by those features found during the excavations within the environs of Crediton Parish Church, Devon, in the 1990s (Allan et al. 2011, 114). Pits, 0.3-0.6m deep, to the rear of a dwelling, are attributed to domestic clay extraction before the 15th century. Hundreds of similar pits must have been encountered in similar investigations across England, but only a few find their way into the Historic Environment Record (HER) and there is no known systematic survey of such discoveries.

Most historical and archaeological investigations specific to clay extraction have been on sites of post 1750 date and most were carried out in Southwest England. Research is dominated by the investigation of china clay working. Cornwall Historic Environment Service (CHES), formerly the Cornwall Archaeological Unit, CAU), have been responsible for most of the archaeological work, but publications such as Barton's *A History of the Cornish China-Clay Industry* (1966) and more recent historical research by various individuals, and groups such as the China Clay History Society, have helped inform that work. Early work on the industry included an archaeological and historical survey for the Luxulyan Valley Project (Smith 1988), which incorporated the investigation of a small number of china clay and stone processing sites.

With a china clay industry around St Austell expanding its operations and seeking to rework or consolidate existing sites, there have been opportunities to investigate additional discrete features, following on from an earlier comprehensive archaeological assessment (Herring & Smith 1991). Although Smith (1992) provided an overview of the industry, its history and the known archaeological evidence in Cornwall as a whole, it is in the St Austell area that most of the detailed investigation has been carried out.

China clay working on Bodmin Moor fell within the area covered by the EH Bodmin Moor Archaeological Survey (Herring et al. 2008). The majority of investigations in Cornwall have taken the form of assessments, with limited recording of individual remains (for example, Smith & Buck 1994; Cole 2001; Cole 2005; Cole 2007). At least one report, that for Wheal Martyn (Smith 1999), was in advance of consolidation of features, prior to its conversion to a museum. Some investigations have led to detailed recording, as with the Greensplat engine house (Thomas 2002), the water wheel at the Virginia China Clay Works (Thomas 2000). A report on the Goonvean engine house and its environs (Fig 6.2) is pending. In the case of the Sky Tips around St Austell (Smith 2008), the assessment itself provided a valuable photographic record. Settlements, and their associated cultural infrastructure linked to china clay working, are an acknowledged feature of the St Austell area; that is recognised in the Cornwall Industrial Settlements Initiative studies of Bugle, Roche and Stenalees (Cahill Partnership & Cornwall HES 2005a, b & c).

In Devon, china clay working has attracted the attention of field archaeologists working for English Heritage (formerly the RCHME survey teams), and the results of their work, including some detailed site surveys, was recently published in *The Field Archaeology of Dartmoor* (Newman 2011, 214-22). An evaluation of the Shaugh Bridge works had been carried out earlier in association with the work of the RCHME (Smith & RCHME 1996). A detailed survey of the Shipley Bridge China Clay Works was published in the course of English Heritage's work on Dartmoor (Newman 2002b). The transport links to the china clay works were considered by Wade (1982), but the focus was on the tramway and its working, not the extraction processes. At the time of writing, china clay processing areas and drags in the Smallhanger area have been recorded in advance of destruction by the proposed Hemerdon (tungsten) Mine reopening and the expansion of the Headon Down china clay works (Fig 6.6).

The use of china clay and stone in the production of bricks in Cornwall was touched upon by both Herring and Smith (Herring & Smith 1991; Smith, 1992) and reviewed by Ferguson & Thurlow (2005). In Devon, the use of china clay and low grade iron ores was the subject of a detailed survey of the brickworks at Shaugh Bridge, at Meavy on the southwest border of Dartmoor, and the associated ferro-ceramic mine (Fletcher 2000).

Ball clay working in Devon and Dorset has attracted significant interest but that is largely confined to historical research supported by a large historic photographic record and the conservation of artefacts by groups such as the Ball Clay Heritage Society, which is particularly active in South Devon, and the Purbeck Mineral and Mining Museum, Dorset. For the Devon ball clay workings, Edwards (2011, 106-35) provides a useful geological and historical background. Rail transport associated with the North Devon workings has been investigated by Messenger (2007). The Stover and

Figure 6.10 Derelict waterwheel for powering pumps in a nearby china clay pit, St Stephen in Brannel, Cornwall. Jamed Davies, © Historic England

Hackney Canals, and the associated quay at Hackney, were the subject of an archaeological assessment in the early 1990s (Pye 1991) and an assessment of the Stover Ball Clay Works, in South Devon, was carried out by Adam et al. (2001). However, the latter appears to have taken little account of the archaeology of the extractive processes on the site. In 2014, a first season of archaeological excavations at Ventiford Basin, at the head of Stover Canal, revealed the remains of a probable clay barge of early to mid-19th century date (Newman 2014b).

Fuller's earth was, and to some extent still is, worked by opencast methods in Oxfordshire, Bedfordshire and Surrey. It was also worked underground in the area around Bath in Somerset up until 1979 (BGS 2006b). The history of the Bath workings has been covered by Macmillen (2009) using historical documentation, mapping and observation of the surviving surface features, but there has been no detailed archaeological investigation of these or any other abandoned fuller's earth workings.

Walker's earth, a mica-montmorillonite clay used as a substitute for fuller's earth, is found at several horizons in the Silurian Wenlock Shales of Shropshire, and was worked at Coalbrookdale. Some of those workings were investigated in the 1970s and at least one level was surveyed (Brown nd), but there has been no detailed archaeological investigation.

Outside the southwest of England, there has been very little investigation of the extractive processes. Investigation has centred on kilns and brickworks, and it is unlikely that all of those investigations are listed in the HER. There are some exceptions, as in Norfolk where the late medieval Caister Brick Pits were the subject of an archaeological assessment (Wallis 2007). There has also been identification of clay pits in the course of a wider landscape survey, as in Writtle Forest, Essex (Bannister & Bannister 1993), or Lancashire and the survey of the Bowland Forest Estate (Hodgkinson et al. 1997). Clay extraction pits might also be identified in the course of routine archaeological evaluation but not necessarily investigated (*see* Sommers 2008). Pits associated with brick making in the south and east of England are often subject to evaluation as 'brownfield' sites considered for housing development. All too frequently, however, the presence of clay extraction is seen as rendering the site of little interest to archaeologists, as in the case of the evaluation of the former RAF West Drayton site to the west of London, which stood on the site of brickearth pits - 'The quarrying would certainly have removed any archaeologically relevant levels, the brickearth itself being the relevant layer for Palaeolithic remains' (Hopkins 2009, 10). In many cases, re-use of brick pits for waste disposal has restricted the options. Investigation in advance of housing development can, however, provide some interesting evidence for the extraction processes. That was the case in Dartford, Kent, when a chalk mine, sunk in the base of a brick earth pit to provide supplementary material for brick making, was investigated and recorded (LeGear 2009). Video recordings have been made for a number of brick making, and other, clay industries that continue to use earlier techniques in their operations, including the Claughton Manor ropeway. Those recordings are now archived and might be used to inform future archaeological investigations (*see* I A Recordings 2012 for a list of the archives).

Only in Cornwall has there been any archaeological assessment which encompasses all aspects of the clay industry: the workings, the processing of the clay, and the associated infrastructure of transport and settlement (Smith 1992). Most investigations have focussed on the processes intimately linked to the firing of the clay in the pottery and brick kilns, with scant regard for the source of the raw material or its transport. With regard to transport, a search through publications such as the Industrial Railway Record will produce detailed information on many of the tramways and light railways associated with clay extraction but nothing on the scale of Tonks' (1988-1992) work on the ironstone railways of the English Midlands. The settlement pattern associated with clay extraction is, as yet, an untapped area of research.

Acknowledgements

I have been assisted in preparing this assessment by a number of people with specialist knowledge in various aspects of clay working, including Mike Gill, Derek

Barker, Ivor Brown, John Rowley (Purbeck Mineral and Mining Museum), Tony Vincent and Colin Bristow along with members of the Ball Clay Heritage Society and the China Clay History Society who attended a seminar at Wheal Martyn near St Austell in July 2011.

Notes

1. This section draws heavily on Simco 1998, 11-16, and notes provided for the specialist ball and china clays by Tony Vincent and Colin Bristow, including information in Bristow et al. (2002).
2. Privately published, these two books are of limited circulation and are not available in research libraries.

7 Lead, Silver and Zinc

Dave Williams

Additional material contributed by Jake Almond, John Barnatt, Peter Claughton, Mike Gill, Phil Newman, David Poyner, Geoff Warrington, Robert Waterhouse, and Lynn Willies

7.1 Introduction

This section deals with the elements lead (Pb), zinc (Zn) and silver (Ag). In general, the ores of these metals are of hydrothermal origin and typically occupy vein structures or occur in stratiform bodies, though some minor occurrences are in the form of disseminations. The ores usually consist of the sulphides galena (PbS), sphalerite (ZnS) and acanthite or 'argentite' (Ag_2S). Weathered parts of veins may include lead carbonate (cerussite), lead chlorophosphate (pyromorphite), zinc carbonate (calamine or smithsonite, $ZnCO_3$) and zinc silicate (hemimorphite). Of these, only cerussite and smithsonite can be considered sources of lead and zinc, respectively, in England. Silver is usually present in solid solution in galena in England, nearly always in very small proportions although supergene action close to surface can result in significantly increased silver values in shallow deposits. It is also found, though rarely, as native silver and as discrete silver compounds, silver sulphides, or in more complex minerals, such as tetrahedrite, in combination with both lead and copper. Occurrences of these minerals in mining districts in England have been documented by Tindle (2008).

7.2 Location

The main lead, zinc and silver mines occur in seven principal orefields in ten counties of England. Those in Devon and Cornwall comprise the Cornubian orefield; in Devon the main deposits lie around Dartmoor, in the Teign Valley to the east, around Plympton, to the southwest, and Mary Tavy and Bere Ferrers to the west. However, there are lead mines in the north of the county, at Combe Martin and near South Molton, Swimbridge and Bideford, that are outside the orefield associated with Cornubian granite emplacement. In Cornwall, lead mines exist at Menheniot, East Wheal Rose, Newlyn, Mount's Bay, St Agnes, Porthleven, and Silver Valley, south of Kit Hill; some mines near Newquay worked ore bodies that predate the granite emplacement. (Nb: the N/S crosscourse veins with lead in Devon and Cornwall are much younger than the granites and their associated tin and copper mineralisation; see Scrivener et al. 1998). The Mendip orefield is confined to Somerset and the outskirts of Bristol; the principal mines are located near Charterhouse and Priddy. In Shropshire the lead orefield is mainly on, or slightly west of, the Stiperstones Ridge. Lead mines occur throughout the White Peak area of

Figure 7.1 The 60-inch pumping engine house of 1868, set amid the spoil heaps at the head of Job's Shaft at Wheal Betsy is one of Devon's iconic mining structures. The mine produced lead, silver and probably some zinc. © Phil Newman

Figure 7.2 A complex of worked veins above Cressbrookdale in Derbyshire. © Dave Williams

Derbyshire, and in a small adjacent area in Staffordshire. The Yorkshire lead mines are to be found throughout the Yoredale formations of the Dales, particularly at Grassington Moor, Greenhow, Wharfedale, Wensleydale, Swaledale and Arkengarthdale. The North Pennine lead, zinc and silver orefield covers Teesdale and Weardale. In Northumberland mining took place at Allendale, around Haydon Bridge and near Blanchland. In Cumbria, lead mines are in the east, around Alston Moor and Nenthead, and along the western escarpment of the Cross Fell massif. To the west, a small orefield existed in the Lake District, where lead was mined in Patterdale, on the Caldbeck Fells, and around Keswick. The character of these orefields, with relevance to the mining techniques, has been summarised by Cranstone (1992a, 11-15).

Minor occurrences of lead and other ores also occur in the Triassic rocks of the Midlands in Cheshire, North Shropshire, South Derbyshire and Leicestershire. Although lead mineralisation was recorded at a number of small mines in this region, few have produced the metal, and for those that have, including Alderley in Cheshire, the output was insignificant.

7.3 Consumption and production

7.3.1 Lead

Lead has been produced in England since the Bronze Age (*see* Section 2.6.1), and evidence of its likely production in the Mendips in the Iron Age has also been recorded (*see* Section 2.6.2). Silver rarely occurs in a native form, and, with no evidence as yet for pre-Roman extraction of silver from lead ores, it is likely that the few silver artefacts of that age found in Britain were imported.

The accelerated exploitation of lead and silver resources commenced in the Roman period. Pliny noted in the 1st century AD, that 'In Britain it is found in the upper layer of soil and in such quantity that a law was passed without protest, prohibiting the extraction of more than a fixed amount' (Pliny the Elder 1992). Roman mining is known to have taken place in the Mendips, Shropshire, Derbyshire and Yorkshire where pigs of lead have been found in all these areas (*see* Section 2.6.3), and it is thought to have occurred at the Engine Vein Mine, Alderley Edge, in Cheshire (Timberlake & Kidd 2005).

Lead mining appears to have declined significantly, if it did not cease altogether, after the departure of the Romans. It is unclear how much lead was available to be robbed from abandoned buildings, when demand resumed in the post-Roman period: there is some evidence that recycled lead was already being exported at the end of the Roman period (Claughton 2011, 58). However, a revival in lead mining began in the 7th century AD, with lead being used increasingly for construction purposes, and Derbyshire was a significant centre of production (Claughton 2011). The Domesday Book refers to the Derbyshire lead industry (Morgan & Wood 1978), but information on similar taxable production is lacking for other areas, particularly the north of England. Evidence from smelting sites in the north of England suggests that lead was being worked across that area from the 10th century onwards and, by the 12th century, the North Pennines, Yorkshire, Derbyshire and Shropshire orefields were contributing to an increasing trade in lead (Claughton 2009). From this time, and into the medieval period, the greatest consumption of lead was for ecclesiastical buildings and coffin-making; examples of the latter have been found at many early cathedral and monastic sites (Raistrick & Jennings 1965). The constructional uses were for roofing and as a form of mortar for bonding masonry in fortifications, such as at the White Tower in London. (B Gilmour *pers comm*). Also, a quantity would have been used for leaded glass windows, soldering, alloyed with tin to make pewter, and in jewellery.

The recovery of silver was practiced throughout this period (Rippon et al. 2009; *see* Section 7.3.3).

In 1485, Henry VII granted rights to mine in 'all his mines of Gold, Silver, Tin, Lead and Copper in England and Wales' (Pettus 1670, 19), and in 1498 he gave the Duke of Devonshire permission to work silver near Chulmleigh in Devon (Slader 1965).

Production of lead declined after the release onto the market of large amounts of the metal stripped from the roofs of ecclesiastical buildings during the dissolution of the monasteries in the 1530s (Blanchard 1995). This trend was reversed in the post-medieval period by a demand for lead in the recovery of silver from copper ores by the *Saiger* process in central Europe. This, and the introduction of gunpowder as a propellant creating a demand for shot, removed large amounts of lead from the stock capable of being recycled (Burt 1995, 32-34). Cast lead continued to be used for water management, in both supply and waste systems, and many churches and high status buildings were adorned with lead cisterns and downspouts in the post-medieval period. During the 15th century, an innovative use was in creating the type for the newly introduced printing press. There was also an active export trade from ports in the east of England, including Hull, Newcastle, and Yarm on the River Tees (Raistrick & Jennings 1965). In this period the principal lead-producing orefield was Derbyshire.

The consumption of lead continued to rise over the next four centuries. It continued to be utilised for shot, typesetting, roofing and drainage, but new applications were in the manufacture of red and white lead for use in paints and pigments, and in electrical equipment, as cable sheathing and battery plates. In the 20th century, lead was used for shielding radioactive sources and as an additive in petrol. It has also been used where a great weight is required, as in the counterweight for sash windows and for balance weights. Large amounts were used in the run-joints of cast-iron water pipes.

Silver continued to be extracted from lead ores wherever there was enough silver in the ore to make the process worthwhile. Increased efficiency resulted from the introduction of the Pattinson process, patented in 1833, and the Parkes processes in the 1850s (Tylecote 1992) (see Section 7.3.3).

7.3.2 Zinc

Prior to the 19th century, the main demand for zinc ore was for unprocessed calamine used for alloying with copper to produce brass. Later consumption was as metallic zinc, also an ingredient of brass, but used in large quantities for rust-proofing iron and steel, including galvanising iron sheeting after the hot dipping process was patented in 1837 (Day 1998).

In the UK, zinc production had two main phases. Calamine, otherwise known as smithsonite (zinc carbonate), was worked around the Mendips from the late 16th century, following its discovery in 1566, and in parallel with attempts to develop an English copper industry. Production at the first English brass works to utilise the metal, at Bristol, came much later, in the 17th century (Day 1973, 32). Because the metal vaporised before it became molten, and rapidly oxidised to a powdery material on contact with air, calamine was not smelted into zinc, but used in a roasted (calcined) state with pellets of copper and charcoal in sealed vessels.

Zinc metal was rare until the 1740s, but in 1738 William Champion developed a process for making metallic zinc by heating a mixture of calamine and charcoal in large sealed crucibles, and distilling the fumes in water. In the 18th century, mines in Derbyshire, at Castleton, Cromford, Bonsall and Wirksworth (Robey 1994, 12-14; Rieuwerts 2007; 2008; 2010; Ford 2008; 2010; 2012), Malham in the Yorkshire Dales (Gill & Squirrell 2014), and in North Wales, were supplying calamine to the brass makers based at Cheadle in Staffordshire.

Calamine was still being worked in the 1830s-40s, though probably as a small part of zinc output by then. Buildings and mine remains associated with calamine production have been recorded in and around Malham in the Dales (Gill & Squrrell 2014), and a 'Calamine Pit' is known at Bowland-with-Leagram, in Lancashire (M Gill *pers comm*). At Cobscar Mine in North Yorkshire, a 'Calamine House' or calciner survives and is now a scheduled monument (NRHE No. 34827). Calamine mines are also known in the Mendip orefield, where Singing River has been a focus for investigation (Richards 1971, 7-9; Schmitz 1976, 81-3).

Another important advance came in 1758, with the development of a process for smelting zinc from roasted sphalerite (zinc sulphide), often referred to as 'blende', an ore which was more plentiful than calamine and often occurs alongside galena in certain mineral veins.

Sphalerite was often considered a low value mineral and a nuisance at lead mines, where it was particularly difficult to separate using gravity methods. Generally, it was thrown away when separated as part of the 19th-century lead dressing processes. However, when prices were sufficiently high to make its recovery economical, it appears to have been worked where veins had been left unworked by lead miners, or where it had been separated and stowed in old lead workings, or tipped in surface spoil heaps. In a few cases blende was mined alongside galena. A few British mines, largely developed as lead workings, were able to exploit blende in this way. Many of these were in Wales, but in Devon, Silverbrook Mine, Borringdon Consols and the mines in the

Teign valley, though worked principally for lead, had a recorded output of zinc in the 1850s (Burt 1984), while mines in Cumbria, including Nenthead, produced over 9000 tons of zinc ores per annum from 1856 onwards (Burt et al. 1982).

7.3.3 Silver

In most cases, the evidence for mining of silver-bearing ores is indistinguishable from that of the mining of lead. There was a continuing demand for silver in coinage, reintroduced into England in the 7th century, with its increased use in commercial transactions. Most silver obtained in England came from lead ores, and distinctive archaeological features are related only to the processing of those ores and, more particularly the lead metal after smelting. Initially, most mining of lead ores was carried out with a view to extracting the silver, the value of which often exceeded that of the lead, and the earlier mines were, up to the end of the 12th century, effectively silver mines. From the 13th century onwards, mines which continued to return high silver values, for example those at Bere Ferrers in the Tamar Valley of West Devon, were technologically advanced when compared to non-argentiferous workings, and present some distinctive archaeological evidence. Pettus (1670, 7) noted that silver was produced from the mines of the Triass of Cheshire.

Although most silver in England was extracted from lead ores, there is a small group of mines in East Cornwall, in the western part of Calstock parish, which worked rich silver-bearing ores, including acanthite ('argentite') and other silver sulphide minerals (Jenkin 1976, 24-31; Dines 1956, 636). The ores were first noted in the 16th century but successful working was confined to the early 19th century. Two mines in the group, the Prince of Wales Mine and Wheal Brothers, have been investigated in archaeological assessments carried out by Cornwall Historic Environment Services. There are, however, no features present (nor to be expected) on those sites, other than the lead-silver smelter erected in the 1830s, that differ markedly from those associated with the deep mining of the tin and copper ores that are also found there and at neighbouring mines (Buck 2006c, 2008a).

7.4 Geology

Mineralisation in many of the orefields resulted from the injection of heated and pressurised solutions into joints and fissures caused by earth movements in the late Carboniferous period. The engines driving this process include, for Derbyshire, 'seismic pumping' of solutions from deep under the North Sea (Worley & Ford 1977), and in other areas, convection currents associated with Variscan (late Carboniferous to early Permian) granites. Different minerals crystallise out at different temperatures, resulting in zoned deposits in the joints and fissures. Some solutions may dissolve the country rock and produce replacement deposits adjacent to joints and fissures.

Lead and zinc ores occur principally in hydrothermal veins, though the host rocks vary depending on the region. In Devon and Cornwall the host rocks are of Devonian age: there, the majority of the lead veins or 'lodes' are in north-south crosscourses that lie at 90° to most of the tin and copper lodes and occur in the metamorphic killas zones, as in the Teign Valley. However, east-west lodes are known in association with copper at St Agnes (*see* Dines 1956); this is also seen at Plympton, Devon, and Silver Valley, Cornwall. The crosscourse mineralisation is of Mid-Triassic age, and formed from low-temperature high-salinity fluids that originated in Permo-Triassic sedimentary basins (Scrivener et al. 1994). The lead deposits in North Devon and West Somerset, on the borders of Exmoor, and probably those immediately to the south-west of Newquay in Cornwall, are stratiform deposits of syngenetic origin that predate the Cornubian granite emplacement (Beer & Scrivener 1982, 123; Scrivener & Bennett 1983). In the Mendip region, silver-lead veins occur in the Carboniferous Limestone, principally around Charterhouse.

Along the Pennines, lead- and zinc-bearing veins occur in Carboniferous limestones, cherts and sandstones. The Shropshire orefield occurs in rocks of Ordovician age on either side of the Shelve anticline, whilst further north, the situation in the Lake District is more complex. Around Keswick, veins are hosted by Cambro-Ordovician age rocks, but veins in the Helvellyn and Caldbeck Fell areas are found in Ordovician volcanic rocks.

In some cases, mineralising fluids were trapped below impervious beds to form rich wing deposits (flats), whilst in others, veins have been displaced or truncated by faults and dykes. Lead mineralisation also occurs, particularly in the Peak District, as primary deposits in palaeo-karst caves, where they are known as pipe-works. In other places, called 'pipes' by miners, later caves cut through and eroded mineral deposits, resulting in redeposition of mineral-rich sediments elsewhere in the cave system. Surficial and supergene ore-forming processes enhance silver content along some veins, but this may be subject to erosion (Robb 2005). Ores of lead, including silver-rich ores, have also been found as float deposits following the physical weathering of country rocks at surface, as in East Cumbria, at Chesters, near Tynehead (Dunham 1990, 69, 71, 129) and, in some instances in Derbyshire, possibly

Figure 7.3 Aerial view of Old Moss Mine on Grassington Moor in the Yorkshire Dales showing finger dumps of waste. © NMRS

underground (Rieuwerts 1991).

The Midlands deposits include lead and minor amounts of zinc, silver and other minerals associated with, but usually subordinate to, copper mineralisation. They occur at scattered sites in Cheshire and North Shropshire, in the post-Carboniferous Cheshire Basin (e.g. Warrington 1980b; Carlon 1981a; Plant et al. 1999), and in South Derbyshire and Leicestershire (King 1968, fig.24).

7.5 Historical research

Specialised interest in recording the history of lead and zinc mining commenced in the 19th century with the work of Forster (1821), Farey (1811), Murchison (1876), Wallace (1890), Sopwith (1833) and others. In the later 20th century, specialised books aimed at a wider audience became available, including *A History of Lead Mining in the Pennines* (Raistrick & Jennings 1965; Raistrick 1973), *Derbyshire Lead Mining through the Centuries* (Kirkham 1968), and *The Lead Miners of the Northern Pennines* (Hunt 1970). However, some of these books are now rather dated – although *The British Lead Mining Industry* (Burt 1984) has stood the test of time – and there is a need for some revised histories. Up-to-date material has been produced for some regions, as with *Lead Mining in the Peak District* (Ford & Rieuwerts 2000) and *The Lead, Copper and Barytes Mines of Shropshire* (Shaw 2009).

Lead and zinc mining has been at the forefront of research effort amongst mining historians and archaeologists in England, comparable in volume with that on tin, copper and iron. This may be because of the relative ease of access to both surface and underground remains compared, for example, with coal mines. As a result, several regional societies have grown up dedicated to the research and preservation of lead mining remains and a large corpus of newsletters, journals, books and theses has become available, providing much and varied information.

Several of the lead mining districts lie either in, or partly within, National Parks - including the Peak District, the Yorkshire Dales and the Lake District - or in Areas of Outstanding Natural Beauty (AONBs), such as the Mendip Hills, Nidderdale and the North Pennines; the lead mines of Cornwall and some in West Devon are covered, together with other mining remains, by the Cornish Mining World Heritage Site. In all these areas, relevant bodies have commissioned landscape, archaeological and historical reports on lead mining remains. The results of many have been produced in 'grey' format, although some may lie unpublished within archives.

In the 1950s, an increasing number of cavers, and

Figure 7.4 Southwest Shropshire contains a small cluster of lead mines west of the Stiperstones district. This engine house at White Grit Mine is one of several that survive in an upstanding state. © Phil Newman

other enthusiasts, began exploring English lead and zinc mines and recording mining remains; by the early 1960s they had formed societies which specialised in mining history.

7.5.1 The orefields

An account of the West Shropshire Mining Region (Dines 1958) led, in part, to an interest in the Shropshire lead mines among individuals who, from about 1960, formed the Shropshire Mining Club (later the Shropshire Caving and Mining Club). From that time, a series of publications has been produced detailing research into the history and archaeology of the mines in the county (Adams 1962; Brook & Allbutt 1973; Brown 1976, 1990, 1993a, 1993b; Pearce 1995; Shaw 2009), and a gazetteer by Pearce (1994) lists the metalliferous mines of the county. Snailbeach Mine, and its associated smelt mill, constitute the most complete preserved example of a 19th century lead mining surface complex in Britain, and is protected as a Scheduled Monument.

The Peak District National Park, which covers parts of Derbyshire and Staffordshire, contains arguably the best researched of the English lead orefields. An inventory demonstrating the former extent of lead mining sites, along with those surviving and considered of regional and national conservation importance, has been published by the Peak District National Park Authority (PDNPA) (Barnatt & Penny 2004; Barnatt et al. 2013, 1-112). An early trailblazer in Derbyshire was Nellie Kirkham who published a large number of articles in publications as diverse as *Cave Science*, the Peakland Archaeological Society *Bulletin,* Derbyshire Archaeological Society *Journal* and the PDMHS *Bulletin* (see below) before producing *Derbyshire Lead Mining through the Centuries* (1968; see Nash 1978). The Peak District Mines Historical Society (PDMHS) has been publishing a bi-annual journal, *Mining History* (formerly *Bulletin of the PDMHS*), for fifty years[1]. This, together with a number of special publications, which include a reprint of Stokes' *Lead and Lead Mining in Derbyshire* of 1880-1883 (No 2, 1996 edition), has provided numerous detailed accounts of the history, geology and archaeology of mining in that district and beyond. Parker and Willies (1979) published annotated photographs of surface and underground features of Derbyshire mines. A prolific writer on the Derbyshire orefield is Rieuwerts who, in his *Lead Mining in Derbyshire: History, Development and Drainage* series, has provided historical accounts for Castleton to the River Wye (2007), Millers Dale to Allport and Dovedale (2008), Elton to the *Via Gellia* (2010), and Cromford and Wirksworth (2012). The same author has, with Ford, edited and contributed to a general account and guide to Peak District lead mines (Ford & Rieuwerts 2000). Extensive contributions on the geology and other aspects of Derbyshire lead mines have been made by Ford (e.g. 2001; 2005b; 2008; 2010; 2012). Lead mines of the Manifold valley have been covered by Porter and Robey (2000).

Willies has written extensively on surface evidence (1975; 1977; 1991), including that for water power (2004), ore dressing and smelting (1991; 1998), and in a history of Magpie Mine (Willies et al. 1987). Kiernan (1989) has reflected on the 16th-century lead industry. Barnatt (2002a; 2003; 2009), Barnatt and Worthington (2006a; 2006b; 2007; 2009) and Palmer and Neaverson (1989) have all examined the archaeology of lead mining sites in Derbyshire. The PDMHS founded and maintains the Peak District Mining Museum at Matlock Bath, together with a library, archives, and collections. The Peak District is well served by historical archives at Sheffield, Matlock, Chatsworth and the Public Record Office at Kew. Other museums with lead mining displays are the Buxton Museum and Art Gallery, the Wirksworth Heritage Centre and the Silk Mill Museum in Derby.

The first overview of the Yorkshire lead mining fields was written by Backhouse for the *Victoria History of the County of York* (Page 1912). Probably the county's best known writer on, and publicist for, lead mining was Arthur Raistrick; a polymath, he wrote papers and books on the topic between 1927 and 1983, and made major contributions to geology, especially palynology and glaciology, archaeology, history and landscape studies. In the 1940s, potholers led by Eli Simpson (1884-1962) of the British Speleological Association began looking at

lead mines, especially where they were associated with caves. Nothing of significance was published, but some useful archives were amassed. However, one of their number was Bob Clough who wrote on lead smelting mills in the Yorkshire Dales (1962;1980). Since 1960, the history and archaeology of all aspects of Yorkshire's lead mining fields have been researched by members of the Northern Mine Research Society (NMRS), which has published their findings in the *British Mining* series[2]. Gill has written detailed monographs on mining in the South Craven and Bowland areas (1987), Grassington (1993a; 2010), Wharfedale (1994), Greenhow (1998) and Swaledale (2004a). Tyson has covered the Marrick (1989), Grinton (1995a) and Arkengarthdale mines (1995b). Their work, which includes numerous other papers, has both amended that of earlier writers, such as Clough(1962; 1980) and Raistrick (1975), and produced much new material. An important paper by Spensley (2010), on the historical development of lead mining in the Wensleydale area to 1830, must be included with the foregoing. Landscapes, including 'underground landscapes', have been covered by Gill (2000c), Roe (2003c; 2007) and White (1989;1995).

Mining museums, and dedicated collections and displays in local and regional museums, play an important role in the interpretation of lead, silver and zinc mining. For Yorkshire, there was, until September 2015, the Yorkshire Dales Mining Museum at Earby (now closed) but other, smaller collections survive in the Craven Museum at Skipton, the Nidderdale Museum at Pateley Bridge, the Dales Countryside Museum at Hawes, and the Swaledale Museum at Reeth.

There is a scattered group of small lead mines outside the main Yorkshire orefield, which includes those at Cononley in North Yorkshire, and the Forest of Bowland, Thieveley and Anglezarke in Lancashire. Information on these areas is included in Gill (1987).

The history of the Northern Pennine lead and zinc orefield has also been researched by members of NMRS and by groups attached to the museums at Killhope in County Durham and Nenthead in Cumbria. However, coverage is still patchy. Early published work includes Raistrick and Jennings (1965) *History of Lead Mining in the Pennines*. Fairbairn has published monographs on the mines of Weardale (1996), Allendale, Tynedale and Derwent (2000), and Upper Teesdale (2005). The north-east of England has been explored by Turnbull (2006), and additional historical information may be gleaned from Dunham (Dunham 1990). Archaeological excavations have been carried out at Killhope (Cranstone 1986) and Nenthead (Critchley 1984). Site histories and field descriptions for a large number of lead mines along the western escarpment of the Pennines have been published by Smith and Murphy (2011).

Figure 7.5 A meer stone of Geo. Fletcher and Co. on Grassington Moor in the Yorkshire Dales. Such stones were used to mark the extremities of mining leases or 'meers'.
© NMRS

The Lake District lead orefield has been researched by members of Cumbria Amenity Trust Mining History Society (CATMHS), whose several articles are published in their journal *Mine Explorer*. There are also numerous works by Tyler (1989; 1990; 1992; 1995), although that author's otherwise useful ouput is marred by a lack of references. A general view of Lakeland mining was produced by Shaw (1975). Historical aspects of Greenside Mine have been published by Murphy (1996), and of Bannerdale Mine by Hewer (1984). Baugh Fell mines were discussed briefly by Lancaster (1989).

The Cornubian orefield has poor coverage for lead, zinc and silver; historical accounts for West Devon and the majority of Cornwall being devoted largely to copper and tin. Mostly, the topic is included in more general books on mining, including work covering Devon by Hamilton Jenkin (2005), and on Dartmoor by Harris (1968). Schmitz (1980) has published research focusing on the mines of the Teign Valley, complementing earlier work by Ramsden (1937), while Rippon et al. (2009) have put historical research to good purpose in relation to a landscape exploration of the Bere Ferrers medieval silver mines. Mayer (1990) highlighted the value of the documentary record for Bere Ferrers and its association with smelting at Calstock on the Cornish bank of the Tamar. These areas have also been explored historically by Claughton (1996), and mines of Dartmoor and in

Figure 7.6 An open cut lead working on Major Vein, Oxlow Rake, Peak Forest. © Dave Williams

the Tamar valley have been recorded and published by Richardson (1995). Away from the Dartmoor granite, there are smaller mines, such as that at Newton St Cyres (Pamment & Slater 1988), and others in North Devon (Slader (1965; Stukey 1965; Claughton 1994; 1997a).

In Cornwall, lead mining, unlike tin and copper, does not have a dedicated literature. This is probably because lead in this district comes mostly from mines also worked for the other ores; the histories were usually integrated by researchers, including Booker (1968), who mentions lead, silver and zinc (blende) merely in passing. However, Buckley has included lead mines in his major work on Cornish mining (2005) and claims that although over 200 mines may have produced lead in that county, most of it was raised from just five mines (*see also* Burt 1984). Amongst those was East Wheal Rose, for which a short history has been researched by Douch (1979), and mines of the Menheniot area in East Cornwall, covered by Bartlett (1994).

The Mendip orefield has a history of Roman exploitation for both lead and silver, but despite a well-developed tradition of underground exploration by various organised groups, including the Mendip Caving Group and Bristol University Speleological Society, post-Roman historical research is largely restricted to Gough's (1967) general history. The historical background for 19th-century reworking was investigated by Stanton and Clarke (1984), and some cavers have been inspired to investigate the origins of the workings they were exploring (see Section 15). However, recent archaeological activity by the independent Charterhouse Environs Research Team (CHERT), has made a start on archaeological survey of the lead mines there.

7.6 Technology

Lead mining, dressing and smelting techniques have been described by Burt (1984), Cranstone (1992a & b), Willies (1975; 1990; 1991;1992), Martell and Gill (1990) Gill (1992; 1993b), and in numerous volumes focusing on specific mines or orefields (see above) where local variations may exist. In general, aspects of technological progression identifiable in the extraction of lead and zinc are shared by other non-ferrous metals, including copper and tin, though not necessarily synchronously. Also, the history, traditions, terminology, and to some extent the archaeology, of lead mining in Britain are subject to considerable regional variation.

In most orefields of England, some form of customary law was practiced as a means of apportioning the workable land between miners, and would have been influential on the formation and development of the mining landscape. Customary mining law has origins before the Norman Conquest, and, with some variance from region to region, enabled miners to search for lead unhindered, and lay claim to veins upon their discovery, subject to certain conditions. The standard unit of land to work lead along the vein was the 'meer', which varied in size but was commonly around 30-32yds (29m) long (Gill 1989; Ford & Rieuwerts 2000). A space, known as the 'quarter cord' (i.e. quarter of a meer) was allocated either side of the vein to give the plot the form of a rectangle. Within this plot, all the miner's activities had to be contained, including dressing ore and stacking waste. Field evidence, comprising narrow strips containing waste, including dressing waste, either side of an extraction trench, has been recorded at Fielding Vein, in North Yorkshire; this has been interpreted as surface expression of working within the constraints of the quarter chord (Roe & Davies 2000). A transition from the system of customary law occurred, depending on area, from the late 17th century. In Swaledale, time-limited leases were introduced before 1700, when customary law was abandoned (Gill 1988b). Here, and later at Grassington, the size of the quarter cords increased and in some cases several were amalgamated. Customary law was abandoned in most areas in the 18th century, notably Grassington, where leases of larger blocks, though based on multiples of the meer system, has been recorded (Gill 1993, 18-24). Archaeologically, these changes, and subtle chronological and administrative

changes in other orefields, will have certainly affected the character of the field evidence.

7.6.1 Extraction

Lead veins, or rakes, often run (strike) across country and, as is the case with most primary metallic deposits, early exploitation is evident from disturbance on the surface, running across the landscape following the strike of the vein. These earthworks represent the earliest surviving field remains of mining on such veins from where ore was removed by digging trenches, or shafts of limited depth, along the upper sections of any deposit shallow enough to be worked in this way. The appearance of these workings varies, but may comprise linear alignments of small pits and amorphous hollows, surrounded by hillocks of waste material, now often partly smoothed by an overgrowth of turf. Alternatively, surface working was carried out in long narrow trenches: these may survive as earthworks but in some places they have vertical sides, giving the appearance of quarry-like workings, with closely spaced, roughly parallel rock faces marking where vein material has been removed. An example survives at Dirtlow Rake near Castleton (Ford & Rieuwerts 2000, 66-7). The surface evidence on some lead rakes may be a combination of these types of remains, but all have in common the limited penetration of the working, whether underground or open to the sky. Remains of these workings are very evident in orefields in the Peak District, Cumbria, Yorkshire and the Mendips. These sites cannot be dated on field evidence alone, but documentary coverage of the industry in areas such as Derbyshire, suggests some opencast workings, including Tideslow Rake, are of 13th-century date (Ford & Rieuwerts 2000, 24); it seems likely that most have medieval or post-medieval origins, though some may well be earlier. Some Mendip lead workings of this type are proven to have been active in the Roman period (Todd 1996, 2007).

In Devon, in the early 14th century, the development of deeper drainage adits reduced the reliance on manual water haulage using leather buckets (Rippon et al. 2009, 79-84). By the third quarter of the 15th century the demand for silver, the depth of the mines at Bere Ferrers, and the high cost of manual labour in hauling water and driving ever-longer adits, combined to stimulate the introduction of mechanised pumping (Rippon et al. 2009, 109-19). Rippon, Claughton and Smart (2009) investigated the evidence for these technological advances linked to the working of silver-bearing ores, and identified related features in the field.

The depth of early workings was restricted by the limits of available hoisting, winding, pumping

Figure 7.7 Racketgill Hush on the east of Hudeshope, Teesdale, Durham. Probably created in the 18th century. The smaller leats are feeding water from adjacent valleys into the main excavation. © Peter Jackson

Figure 7.8 Earthwork remains of a horse gin circle at Red Butts Mine Tideswell in Derbyshire. © Dave Williams

and ventilation technology. As workings progressed deeper, vertical shafts were sunk along the vein and horizontal drainage levels (referred to as 'adits' in some mining districts, though usually described as 'soughs' in Derbyshire and occasionally in Yorkshire) were driven in from low-lying valleys. However, it was not until the 17th century that such techniques were widely employed away from the silver-rich mines of the Southwest. To improve ventilation and drainage of the mines, shafts and levels were frequently connected below ground. Later mines often reworked veins previously exploited using the techniques described above, and shafts, with associated spoil mounds and surface installations for winding and pumping, are often discernible as an intrusion into earlier earthworks.

The vein ore was worked underground by stoping and accessed by internal shafts (winzes) and levels. Driving adits, sinking shafts and working stopes was often aided by firesetting (see Section 15), for which much archaeological evidence has been retrieved (Barnatt & Worthington 2006b; 2007a; 2007b; 2009), although explosives were available from the 17th century, and there is evidence of their use in lead and copper mines (Barnatt 2013, 146-8). A high proportion of the host rocks in which lead and zinc veins occur are competent; this has allowed underground workings to remain in a stable condition and, where entrance(s) are still open, to be accessible for archaeological research.

In Wales, the north of England and Shropshire, but not in Derbyshire or in the Southwest, 'hushing' was used to prospect and exploit the upper sections of veins. This involved using flowing water to expose veins and, perhaps, release and sort the ore by washing away waste. The process left a deep gully or ravine from which ore and gangue had been carried away. Large examples include Colberry in Teesdale (Burgess & Holliday 1979, pl 12), North Hush at Gunnerside Gill (Dunham & Wilson 1985, pl 5), Bunton Hush in Swaledale, North Yorkshire and Roman Gravels in Shropshire. Water to serve the hushes was collected via leats or gutters, often utilising rainwater sources, and captured by dams and in reservoirs, which frequently survive as earthworks close to the hush. The techniques and field remains have been examined in the Northern Pennine orefield by Fairbairn (1992; 2002) and Cranstone (1992b); the latter suggested many were of 18th-century date. Investigations in Arkengarthdale suggests that working by hushing (e.g. Dunham & Wilson 1985, pls 2, 3, 6-8) was only effective where the veins had first been exploited using conventional methods of sinking shafts and levels (Martin Roe *pers comm*). In 1964, Geological Survey staff revived the practice of hushing near Cross Fell (Anon 1965, pl II).

7.6.2 Sources of power

Horses were a major source of motive power for the lead industry. They were used on the surface for pulling skips on tramways to move lead ore, waste and mining materials. In the north of England they were used underground, where horse levels were the main means of access to the mines. Horses were frequently harnessed to drive winding and pumping apparatus, using horse gin or whim setups, and in the Peak District, they provided similar circular movement for breaking ore on crushing circles.

Water power was used widely in the North Pennines, Yorkshire, Lake District and Cornubian orefields. In these districts the topography and high rainfall enabled extensive use of waterwheels for pumping and draining mines, raising ore and spoil to the surface and powering crushing mills, dressing floors and

their associated processes. Leats and reservoirs were constructed and, with the wheelpits, survive as evidence of these installations. A complex water management system of this type on Grassington Moor has been described by Gill (2004b), and other notable examples of water-powered mines are Nenthead and Killhope in the North Pennines. At Wheal Betsy in Devonshire, in combination with neighbouring Wheal Friendship, 17 waterwheels were recorded in use in 1838 (Watson 1843, 55). Water power was of more limited use in other orefields, such as Shropshire, the Mendips and particularly Derbyshire, where water supplies were at a premium. Willies has discussed some of the reasons for the limitations of water usage in Derbyshire mining (Willies 2004). However, water was widely used in Derbyshire to power water pressure engines for pumping, and the greatest concentration of these engines was around Alport; one, illustrated *in situ* in Wills Founder Mine by Willies (1977, 186-7), is now on display in the Peak District Mining Museum at Matlock Bath. Other examples were installed in Swaledale, including at the Sir Francis Mine, at Coalcleugh near Nenthead, and in mines around Allenheads. Examples have been described by Willies (1977; 2004), Carlisle and Gill (2004) and Roe (2004). The use of water power at a number of lead mine settings was published as the proceedings of a conference in 2002 (Claughton 2004a).

From the 18th-century, steam power was used for pumping and winding in all the major lead orefields, with the possible exception of the Mendips. In Shropshire, mining depended upon steam power, as the mines were comparatively deep, and a general lack of surface water meant that several mines had invested in steam engines by the 1780s. There was an adjacent coalfield to provide fuel for these engines, thus making their use economically attractive. There are remains of engine houses at Snailbeach, Tankerville and Roman Gravels mines, amongst others (Fig 7.4). In excess of 100 steam engines were installed in the Derbyshire orefield at various times (Willies et al. 1977). Some of the earliest Newcomen engines were in use around Winster, including engines of 1717 (the 7th oldest), 1719 and 1724; one installed by the London Lead Company at Mill Close Mine in 1748 was illustrated by Raistrick (1977, pl 15). Numerous Cornish engines were installed in this orefield in the 19th century, and the engine house at Magpie Mine at Sheldon is an almost intact surviving example. Whilst remains of engine houses are rare on Yorkshire lead mines, steam engines were widely used in those places where surface water was absent. An example is the surviving engine house at Cononley, surveyed by Roe (2000a). The Cockhill mine at Greenhow Hill had two underground engine and boiler rooms for pumping and winding from deep sumps (Gill & McNeil 1977, 54-6). Many later 19th-century mines around Greenhow used semi-portable high-pressure Robey-type engines. Keld Heads and Cobscar mines in Wensleydale had steam engines. Other engines were at Lane End and the Hurst mines in Swaledale, described by Gill (2000a). There were several engines in use in the North Pennines including Shildon, Presser and Beldon Mines. In Devon, examples of engine houses at specifically lead mines are Wheal Exmouth and Adams, Aller, and Frank Mills all in the Teign Valley, and Wheal Betsy on western Dartmoor (Fig 7.1), which had both pumping and hoisting engines (Nance & Nance 1996, 109). A fine engine house, which once housed a 100-inch engine, survives at Cornwall's foremost lead mine, East Wheal Rose (Douch 1979, 33).

Figure 7.9 The windlass or jackroll was a common method of hauling in shallow lead works, used at surface and below ground over many centuries. © NMRS

Various power sources were used at Alderley Edge, Cheshire, including steam and an oil engine. A windmill was also in use in the early-19th century, to power crushing machinery (Warrington 1981a; *forthcoming*).

Electricity, usually generated on-site, mainly using diesel engines, was used in the relatively few lead mines, such as Millclose, Derbyshire (Naylor 1984; Willies et al. 1989), Greenside in the Lake District, and Nenthead, Cumbria (Critchley 1984), which survived into the 20th century, when their production was a substantial proportion of the national output. The electricity was used for pumping in the mine, raising ore and spoil, or on surface works. Compressed air was used at a few innovative lead mines in the last quarter of the 19th century; water, steam, electricity or internal combustion engines were used to drive fixed compressors, but in the 20th century mobile compressors were increasingly used at all but a few big mines.

Figure 7.10 An early wooden tram waggon which ran on metal rails, now on display at the Peak District Lead Mining Museum. Phil Newman

Figure 7.11 A crushing circle excavated at High Rake Mine in Derbyshire. The crushing stone or edge runner is in the foreground and vestiges of the track are behind. © Dave Williams

7.6.3 Movement of materials

Minerals from lead and zinc mines have mostly been transported by horse-power, either by packhorse or carts. Rural trackways, which either pre-dated the mines or were created to serve them, are common in lead mining districts such as Derbyshire and the North Pennines. Trackways may be seen associated with the mines on Grassington Moor and in Swaledale, while packhorse tracks or 'galloways' are common in the Pennines.

Tramway systems existed in the North Pennine orefield in some of the larger and more centralised mining districts such as Nenthead, and at Priddy in the Mendips. Elsewhere they were not so common, other than for localised use between adits, dressing floors and spoil dumps, although a short (*c.* 315m) surface tramway was built between shafts and dressing floors at Grassington in 1825. From late 1855 until 1888 the Keld Heads Mine in Wensleydale was served by the Leeming Bar to Leyburn standard gauge railway (Raistrick 1975) and, from 1877, Snailbeach Mine in Shropshire was served by its own railway line, the Snailbeach District Railway (Shaw 2009, 58). This ran from 1877, but is generally thought to have been built too late in the life of the mine to have been of any great economic benefit (Tonks 2007). The Cromford and High Peak Railway, across the White Peak area of Derbyshire, may have carried materials to and from mines there, but came too late to be successful. At Borringdon Park, Devon, the mine was linked by cart tracks to the Cann Canal, built *c.*1820 to transport slate from a nearby quarry to the tidal Plym at Plympton, two miles to the south. This was replaced by a horse-drawn railway in 1824, which continued in use throughout the remaining life of the mine (R Waterhouse *pers comm*).

7.6.4 Infrastructure

The infrastructure of the lead mining districts can be divided into two types. In the North Pennines, Yorkshire and the Lake District, geology dictated that the mines tended to be high on the fells away from larger population centres, whereas those in Derbyshire, Shropshire, and Southwest England, were closer to established settlements. The northern mines tended to be staffed by workers from hamlets, small villages and farmsteads. This led to the development of lodging houses at, or near, some more remote mine sites, for example at Langdon Beck in Teesdale and Killhope in Weardale, and in some cases, the development of specialist villages and company rows, as at Nenthead and Hunstanworth. Lead mines in Derbyshire, Shropshire and Cornwall, were rarely far from population centres, which allowed miners to live in the midst of a general population where a wider spread of trades existed. In the case of the silver mines in the Tamar Valley, there is good evidence for the creation of a dedicated settlement at Bere Alston, providing accommodation and markets for the miners from the late 13th century onwards (Rippon et al. 2009, 141-5).

7.6.5 Ore dressing

The manner in which ores of lead, and later zinc, were prepared (dressed) for smelting changed with the smelting technique. The earlier, wind-blown hearths could not treat crushed ore of small dimensions; that had to be smelted in bellows-blown, charcoal-fuelled furnaces at greater cost, both in fuel and the loss of lead through volatilisation. Consequently, only silver-rich ores were so treated on a regular basis (Rippon et al. 2009, 87-100). It was only after the introduction of the ore-hearth process in the late 16th century and, later, the reverberatory furnace, that crushing and washing,

i.e. gravity separation, of ores using buddles etc, became commonplace for non-argentiferous ores.

Lead and zinc dressing floors of varying complexity have been described by Burt (1984), Barnatt (2002a), Cranstone (1986; 1989), Dennison and Haigh (1997), Murphy (1996), Palmer and Neaverson (1989), and Willies (1975; 1991; 1998). Lead dressing floors vary greatly, from the simple buddles and dams in Derbyshire, described by Willies and Barnatt, through to the complex industrial-scale processes at later mines described by Palmer and Neaverson, who also gave a useful gazetteer (though in need of updating). Generally speaking, all lead and zinc ores require cleaning and sorting to some degree. This was nearly always carried out adjacent to the mining sites, where the remains may vary from grass-covered buddles and slimes dams to large areas of waste tailings, structures and ruined buildings. After manual picking, the essential processes for dressing lead ore are washing, classifying, reducing (i.e. crushing) and concentrating using gravity, sieving and, later, flotation techniques, but both the scale and methods associated with these processes varied by region. The following is a general summary.

Ore, once brought to the surface, was stored in stone-built hoppers with, sometimes, sloping interiors, known as bouse teams. These are more common in the Yorkshire and North Pennine orefields (e.g. at Killhope, Gunnerside Gill, Beldi and Old Gang) than in Derbyshire, Mendips or the Cornubian orefield. For the purer grades of galena, only crushing was needed before smelting, whereas, if in a matrix combined with gangue minerals, crushing, washing and sorting were required.

Crushing could be carried out by hand, using flat-faced iron hammers known as 'buckers'. The archaeological evidence of this process sometimes survives as flat-topped stones with slight indentations known as 'knock' or 'bucking' stones. A more automated system, confined to Derbyshire, was the crushing circle comprising an edge-set circular stone (edge runner)(Fig 7.11) driven in a continuous circle over a flat surface, powered by a pony. Remains of a fine example survive at Odin Mine (Ford & Rieuwerts 2000, 71), with the edge-runner and circular track still in place, and a smaller example was archaeologically excavated at How Grove (Barnatt 2002a); both sites are near Castleton in Derbyshire. A description and gazetteer of crushing circles may be found in Barnatt (2002a).

Crushing rollers powered by waterwheels were a later development of the 19th century, but unlike the installations used in the copper industry of Devon and Cornwall, which were always housed in robust stone buildings, at lead mines it was common for the rollers to be placed on stone platforms adjacent to the wheelpit,

Figure 7.12 Killhope Lead Mine in Weardale Co. Durham is now run as a lead mining museum. The large waterwheel once powered a crushing mill. In the foreground are restored Brunton frames. © Phil Newman

as in the example retrieved from Old Providence Mine, Wharfedale (Fig 7.13), until recently on display at the Yorkshire Dales Mining Museum at Earby (*see* Gill 1994). Remains of other examples survive at Killhope, Weardale in Co. Durham, but their survival on English lead mines is rare. Stamping mills were used infrequently at lead mines, though examples are known at Nenthead (Cranstone 1989, 41) and Wheal Betsy in Devon (Pye & Westcott 1992).

A windmill, which was used to power crushing machinery at Alderley Edge, Cheshire early in the 19th century, was replaced by a steam engine in 1807. In 1866, a sale following closure of the nearby Mottram St Andrew mine included a 12-head stamps, and a crusher with two pairs of rolls; the winding-up sale at the Alderley Edge mine in 1878 included a large ore crusher (Warrington 1981a, *forthcoming*).

Ore was concentrated, or washed, using a variety of gravity and sieving methods, which relied on the different densities of the ores and the gangue minerals. This principle was also key to the separation of lighter zinc ore particles from those of the much denser lead ore as part of the dressing process, enabling the former to be retrieved as paying ore at mines worked primarily for lead, though it was often discarded as gangue.

The most commonly-used gravity method of dressing lead ore was the buddle. Early buddles comprised rectangular stone or timber-lined inclined troughs (Fig 7.14), though by the 19th century, circular buddles were used, often providing distinctive field evidence; many survive as circular earthworks at Velvet Bottom near Charterhouse in the Mendips, but they are common in most orefields (*see* Ford & Rieuwerts 2000, 70). Hand methods such as hotching tubs (*see* Ford & Jones 2007, pl 278) and jiggers (*see* Ford &

Figure 7.13 The water-powered roll crusher in situ at Old Providence, Kettlewell in the Yorkshire Dales. It was later removed and exhibited at the Dales Lead Mining Museum at Earby. © NMRS

Rieuwerts 2000, 58) are unlikely to have left much specific archaeological evidence although the areas in which these operations took place, known as washing floors, often survive as artificially levelled terraces, with stone or part-timber surfaces. Water-powered hotching tubs were introduced at Grassington in the mid-1820s by John Barratt (Gill 1988a, 37-50), and water-powered jiggers and Brunton frames (Fig 7.12) were a feature of many later 19th -century lead mines; both were recorded at Killhope (Cranstone 1989). In 1791, it was reported that 'a woman came out of Derbyshire to wash the lead' at Alderley Edge (Stanley 1843, 35); excavations at the site of 19th-century processing works there, revealed features interpreted as a washing floor and the remains of buddles that are shown on the 1872 Ordnance Survey map (Timberlake et al. 2005, 142).

The zinc ore, sphalerite, frequently occurred alongside galena, and in lead mines it was often considered a nuisance. To some extent it could be picked underground and rejected or separated as paying ore using standard lead dressing processes. In archaeological terms, there is no way of knowing (other than from documentary records or by sampling dressing waste) if it was collected as paying ore, or discarded. Archaeological evidence for specific zinc ore recovery might therefore be difficult to distinguish from that of a mine dealing with lead ore only.

It the 20th century, the flotation process (*see* Section 11.10), aided by shaking tables such as the Wilfley (*see* Parker & Willies 1979, pl 68), made it easier to separate the zinc ore, but its low value probably served to relegate it to a minor role. However, it was recovered using these processes at Nenthead, Cumbria, until 1943 (Critchley 1884, 28) and remains of associated buildings survive at this site. Evidence of this technology at mines where lead and zinc ores are known to have occurred could imply that zinc was being recovered as a paying ore, though not with any certainty.

7.6.6 Smelting

Smelting has received more historical and archaeological attention from researchers than some other aspects of lead mining in most regions of England, though coverage for the Mendips, Shropshire, Devon and Cornwall is patchy. General and historical accounts of lead smelting in Derbyshire have been provided by Crossley and Kiernan (1992), Willies (1969; 1990; 1991; 1992), and the Yorkshire smelting mills have been summarised by Clough (1962; 1980), Gill (1992; 1993b; 2000b), and Smith and Murphy (2003). Fairbairn (1993; 1994, 1998) produced articles on smelting in the Pennine orefield, and lesser-known sites in the West Pennines have been identified by Smith and Murphy (2010). A conference proceedings devoted to the topic of lead smelting, and covering numerous aspects of its history and archaeology, was published in 1992 (Willies & Cranstone 1992).

The earliest lead smelters were bole/bale furnaces, which are known to have been in use long before they were first documented in the 12th century (Anguilano et al. 2010). Probably simple structures, made of stone slabs sited on westward-facing slopes, drawing their oxygen supply from the prevailing winds. They relied on a supply of reasonably pure ore, but were quite inefficient, producing large amounts of slag, which might then be reprocessed by smelting in small charcoal-fired, bellows-blown furnaces. Evidence of over 100 bole smelting sites survives in the Peak District alone (Ford & Rieuwerts 2000, 28). Barker (1978) identified 35 medieval lead smelting sites (bales) in Swaledale and Arkengarthdale; one has a carbon isotope date of *c.*1580, but little is known about them. More recently,

Figure 7.14 Remains of a timber buddle at Faggergill. © NMRS

the NMRS has funded a programme of dating carbon residues from such sites. A small group headed by Smith undertook this work, finding new sites and proposing a typology for bale slags (Smith 2006a). The dates fall within the first half of the 2nd millennium AD (Smith 2006b; Smith 2011, 90-107).

In the late 16th century, the introduction of the ore-hearth, a bellows-blown process capable of utilising a range of fuels including kiln dried wood, coal and peat, allowed lower grade crushed ore to be smelted; this resulted in much re-working of lead deposits and the waste discarded during earlier workings. Originally the bellows were driven by human foot power, but by 1572 water power was harnessed for this task. An ore-hearth smelt mill was excavated at Buckden Gavel in 1974 by the NCMRS (Dickinson et al. 1975; Dickinson 1978, 38-9).

The reverberatory furnace, capable of using coal to better effect in smelting lead ores, was developed in the late 17th century and came into widespread use in large smelting operations from the mid-18th century onwards. It was adopted on orefields, such as Derbyshire (Ford & Rieuwerts 2000, 47-8), which were close to coal deposits, and occasionally at more remote locations such as Grassington Moor, in the southern part of the Yorkshire Dales. Most remote upland orefields, as in Yorkshire and the Northern Pennines, continued to use the ore-hearth into the early 20th century. A small number of high temperature blast furnaces were also used at locations where waste dumps of slag and slimes left by earlier enterprises were being re-worked, as at Charterhouse on the Mendips (Fig 7.16) and Alport in Derbyshire. From the early 19th century, long flue systems became a feature of lead smelting operations, improving efficiency by recovering lead otherwise lost as fumes to the atmosphere (*see* Parker & Willies 1979, pls 74-76). Remains of lead smelt mills with the infrastructure associated with fuel supply, including chop-wood kilns and peat stores, survive at Grassington, Marrick, Old Gang, Surrender, Grinton and other sites in the Yorkshire Dales, Alport, Froggatt Wood and elsewhere on the east of the Derbyshire Peak District, and sites such as Hogget Gill in Cumbria. In Devon, at Weirquay near Bere Ferrers, and at Combe Martin, there were specialist silver-lead smelters, features of which can still be identified (Buck 2008b; Claughton 1997a). In East Cornwall, structures which survive at Wheal Langford are probably related to a smelter erected there in the 1830s, but their purpose is unresolved (Earl & Tylecote 1988).

After working in Southeast Spain, a Cornishman named James Mitchell, returned to England and is credited with the introduction of the Spanish Slag Hearth to Britain, erecting the first at Stonedge Cupola, Derbyshire, probably just before 1850 (Willies 1990, 3, 11).

The extent of zinc smelting in England has not yet been assessed but zinc smelters were probably operating at Tindale (Cumbria), between 1845-95 (Almond 1977, 22-40; Smith & Murphy 2011, 11), and Langley (Northumberland) around 1820.

7.6.7 Refining silver-bearing lead

Recovery of silver from lead (refining) came after the lead had been smelted. The process of cupellation was, from antiquity until the late 19th century, the only method used, and field evidence in the form of litharge cakes (the large wood or bone ash cupels, which absorbed a proportion of the litharge [lead oxide] during the process and were discarded after the silver had been recovered), is found occasionally, as in the excavation of the Roman fort at Pentrehyling on the Shropshire - Montgomeryshire border (Bayley & Eckstein 1998). Most litharge cakes were, however, re-smelted to recover the lead; silver might be detected only by analysis of the smelting residues, as carried out in an investigation of the 16th-17th -century smelter site at Combe Martin in North Devon (Paynter et al. 2010).

Medieval refinery sites are known from documentary evidence but have proved difficult to identify on the ground, primarily because the contemporary process of reworking the residues destroyed the evidence (Rippon et al. 2009, 93-99; Claughton & Smart 2010). It is a similar picture for post-medieval silver refining (*e.g.* Paynter et al. 2010) but some 18th-19th-century refining houses survive as recognisable structures; for example, that at Nenthead in Cumbria, with its associated assay house, (*see* Raistrick 1977, pls 3, 5). Archaeological investigation of these sites has been very limited.

In the 19th century, the development of the Pattinson enrichment process improved the viability of silver recovery from lead, and the distinctive plant

Figure 7.15 Ruins of the large peat store at Old Gang Mine in the Yorkshire Dales, showing roof support pillars and open sides. © Phil Newman

Figure 7.16 Remains of the flues attached to the lead smelter at Charterhouse on Mendip in Somerset. © Phil Newman

became a feature of a number of smelting complexes in England. Although elements from the plant survive in museum collections, none can be found *in situ* (Raistrick & Roberts 1990, 73). The site of a Pattinson enrichment plant at the Tamar lead smelter, Weirquay, near Bere Alston in Devon, has been assessed on behalf of Devon County Council as part of a wider brief covering the surviving structures at the two smelters on the site (Buck 2008b, 28-9). Some parts of the Nenthead smelter site, including the refinery, have been cleared and the surviving visible features recorded by North Pennines Archaeology (*publication pending*), but the buildings that housed a Pattinson plant and a later Rozan plant, were not included in that work. The later plant was a development of the Pattinson process, using a combination of steam to agitate the molten silver-rich lead, and cold water to encourage the lead to crystallise out, thus reducing both labour and time. It has not yet been the subject of detailed historical or archaeological investigation.

The Parkes process was only used by large smelting concerns based at remote locations: it took advantage of the affinity between zinc metal and silver to recover the latter from molten lead, thus removing the necessity to use cupellation as the final refining process.

7.6.8 Peat

Peat, or 'turf' as it was alternatively known, was an important fuel for the smelting of lead in some districts, and needed to be cut, transported and stored near the smelt mill. The cutting of peat for smelting has left distinctive features on the uplands in the Yorkshire Dales (Johnson 2009) and is occasionally found elsewhere, as at Wheal Betsy, north of Mary Tavy in Devon, where an area of peat cutting to supply a silver-lead smelting house is recorded high on Dartmoor (Newman 2010). Roads and tracks across moorland, cut specifically to convey peat to the smelter, are a potentially important feature of lead smelting landscapes. Storage was in open-sided structures with roofs supported on stone pillars. These are most common in Yorkshire, at sites such as Old Gang and Surrender in Swaledale (Gill 2001), Keld Heads in Wensleydale and Blakethwaite at Gunnerside but one example associated with lead smelting has been recorded on Dartmoor (Newman 2010).

7.6.9 Regional variation

Much of the mining industry in the north of England took place on unimproved land and the uplands, leaving extensive areas of largely undisturbed remains across the landscape. The practice of hushing, for example, has left many deep scars across hillsides in the lead orefields of the northern counties (e.g. in Arkengarthdale - Dunham & Wilson 1985, pls 6-8). In the Peak District, lead mining took place in both unimproved and farmed landscapes, but, despite widespread contemporary and subsequent land improvement, numerous sites survive with archaeological remains both above and below ground (Barnatt & Penny, 2004; Barnatt et al. 2013).

The Shropshire orefield is, by contrast, dominated by deep mining, reflecting the later development of some of its mines. A legacy of surface mine buildings and remains survive, particularly at Snailbeach and Tankerville, but other types of remains exist across this orefield, and it is known that Roman and medieval lead mining took place there (Cranstone 1992a, 14).

In the 18th and 19th centuries, much of the lead mining in Devon and Cornwall was in deep mines, where the evidence is not easily distinguished from that for tin and copper mining. In Devon, lead ore was mined along the north-south crosscourse veins surrounding Dartmoor and in the Tamar Valley. However, evidence survives of earlier surface working by shallow pits and openworks at the Bere Ferrers (Devon) and Silver Valley (Cornwall) mines. The latter has field evidence for multiple shafts into transitional gunnises/stopes, possibly of 17th century date (R Waterhouse *pers comm*). Evidence for medieval cross-cut adits has been identified in the Bere Ferrers mines (Rippon et al. 2009), and there is some evidence for these in the Silver Valley area as well.

7.7 Archaeology

Published archaeological evidence for lead mining at specific sites prior to the medieval period is limited to the early Roman shallow workings investigated by Todd (2007) in the Mendips, and a small waste heap covered by a supposedly Romano-British orthostat wall at Roystone Grange in Derbyshire (Hodges 1991). The evidence from Roystone Grange has, however, been

Figure 7.17 Archaeological excavations in progress at High Rake Mine in Derbyshire. © Dave Williams

challenged by Chadwick and Evans (2000). Nevertheless, the catalogue of Roman lead pigs listed by Dearne (1990) indicates that there must have been an extensive lead and silver mining industry operating in the Roman period. This is supported by paleoenvironmental evidence from peat deposits (e.g. Mighall et al. 2009), but evidence for earlier lead mining is almost entirely circumstantial and consists of stray finds of lead artefacts. Evidence for Roman mining activity at Alderley Edge has been discussed by Timberlake and Kidd (2005). The metallurgy of prehistoric mining in the British Isles has been discussed by Tylecote (1986) (*see also* Section 2.6).

Claughton (2009) discussed the evidence for the use of lead in buildings and artefacts during the early medieval period, and pointed out that archaeological evidence in support of mining prior to the 13th century is largely remote from the activity itself. For example, a possible pre-Norman or medieval figure of a miner, now in Wirksworth Church, originated from Bonsall Church (Henstock 1999).

There is no general publication covering the archaeology of lead mining in England, other than Cranstone's (1992a) MPP Step 1 report, which focused only on sites considered worth protecting under the policies of the 1980s-90s. More widely, the level of archaeological investigation of lead, zinc and silver mines varies greatly by region, and depends largely on the scale of professional involvement, although the activities of independent archaeologists have made a massive contribution. In general, fieldwork and recording of surface landscapes, and a limited number of underground surveys (*see* Section 15), dominate the work achieved so far, and other forms of investigation, including excavation, have been limited.

The Peak District has the highest number of published reports resulting from archaeological activities, including underground surveys, and an area-wide study has been completed and published by the PDNPA (Barnatt & Penny 2004; Barnatt et al. 2013), mapping and listing lead mining sites across the entire orefield. There has been a long tradition of recording surface features of lead mines, including New Venture (Heathcote 1997a,b, 1998) and Mouldridge (Pearce et al. 1984), both published in *Mining History*.

Detailed landscape surveys have also been carried out by Barnatt (1993a-c; 2004; 2005; 2006); Taylor (1999), Ullathorne (2002) and Bevan and Sidebottom (1995); most of these are in 'grey' format, accessible in the archives of the PDNPA. Archaeological excavation of mining sites is still in its infancy but has occurred most frequently at bole-smelting sites, such as Linch Clough (Bevan et al. 2004)[3] and Totley Moor (Kiernan & Van de Noort 1992); at engine-house sites at High Rake (Barnatt 2011), Silence (Barnatt 2012) and Watergrove (Barnatt *forthcoming*) mines; and on dressing floors at How Grove (Barnatt, 2002) and High Rake mines (Barnatt, 2011). A lead working settlement was excavated in advance of the construction of Carsington Reservoir (Ling & Courtenay 1981). Archaeological recording has also taken place at various underground sites where charcoal for carbon dating has been retrieved from firesetting locations (Barnatt & Worthington 2009).

In Shropshire, archaeological work has been limited to surface recording, mainly associated with conservation work at Snailbeach (Brown 1988; Hannaford 2004, 2006; Hannaford & Price 1995; Truman & Gill 1990). In Cornwall and Devon, where lead and zinc were minor components of an orefield dominated by tin and copper, archaeological research specific to lead mining has not been identified. However, within the general study of the Cornubian orefield, and in particular the research undertaken for the Cornish Mining Landscape World Heritage designation, lead mining is included within surveys of mines where a range of ores were raised. Work towards mapping the surface workings of the 19th century and earlier Silver Valley mines in East Cornwall, has been undertaken but remains unpublished (R Waterhouse *pers comm*).

The archaeology of the silver-lead workings of the

Figure 7.18 Carrs Lead Mine, Nenthead, Cumbria. Pre-1920 end-tipping mine wagon decaying at the work site. © James Heaton

Bere Ferrers peninsula in Devon, and adjoining parts of the Tamar and Tavy valleys, has been studied in a major landscape investigation by Rippon, Claughton and Smart (2009). Fieldwork to record engine houses at mines in Devon, including those sited at lead mines, has been published by Nance and Nance (1996), and Pye and Westcott (1992).

Archaeological investigation in the Mendip orefields has focused on the Romano-British settlement at Charterhouse (Williams 1998; Smith & Brown 2006; Todd 2007; Fradley 2009), where most investigation of mining features has been led by caving interests in the search for 'lost' caverns and mines. Underground features associated with calamine extraction at the Singing River Mine for example were recorded by Richards (1971; 1975), while the Charterhouse Rakes were mapped by Roberts (1982) with a view to further underground exploration. Stanton and Clarke (1984) have mapped many of the surviving features in the Blackmoor and Velvet Bottom valleys associated with the 19th-century reworking of the mines and ancient slag deposits in the same area. Underground work has been carried out further east around Priddy, at, for example, Five Buddles Sink (Jarratt 1997) and Stock's House Shaft (Jarratt 2001), in a search for drainage features used by Thomas Bushell during mining operations in the 17th century. The area around Charterhouse is currently being investigated by Charterhouse Environs Research Team (CHERT), who have applied various survey techniques to the lead mines at Velvet Bottom (Goddard et al. 2009) and continue working there. A useful aerial photographic map transcription of the lead rakes around Charterhouse and Priddy was compiled by Broomhead (2001).

In Yorkshire, the lead mines of the Dales and peripheral areas to the south, have been documented historically in various publications of the NMRS. Very few archaeological surveys carried out in this area have been published, but several NMRS volumes include the results of fieldwork, including plans, maps and, in some cases, of excavations (e.g. Dickinson 1978). As with many areas of northern England, the Yorkshire Dales National Park has been comprehensively mapped as part of the English Heritage National Mapping Programme, which has included a large number of lead mining remains. Fieldwork and mapping of the Dales lead mines was also undertaken by Gill (1993c, d), and lead mines have been included in various rapid assessment surveys such as that for the Nidderdale AONB (Anon 2000). Roe has carried out surveys of Cononley (2000a) and Thieveley (2000b), and published more detailed landscape research discussing the archaeology of these lead mines,

both at surface and underground (2003; 2006; 2007). Ainsworth and Burn (2009) have surveyed Grassington Moor on behalf of English Heritage in order to assess certain threats to the remains.

Minor archaeological works, many of which are in unpublished 'grey' reports, have been carried out by Dennison (1997; 1999a; 1999b; 2002) in Swaledale and upper Wharfedale, by Murphy and Baldwin (2001) on early smelting sites in Swaledale, Smith and Murphy (2003,2010) on similar sites in Swaledale and Nidderdale, while White (1989) has looked at the conservation of mining features. Smelt mill sites have been excavated at Lumb Clough near Keighley, (Dickinson et al. 1975), Buckden, in upper Wharfedale (Dickinson 1978), Old Gang and Surrender in Swaledale (Cranstone 1990; 1991) and Hagg Farm, also in Swaledale (Smith et al. 2014, 2-33). Clough (1980) carried out an architectural survey of many smelt mill sites, which has provided a basis for further study, both historical and archaeological.

The mines of the Northern Pennines have been surveyed historically in various journals published by the NMRS, often coupled with fieldwork, and by the Friends of Killhope. Excavations were undertaken at Killhope and Nenthead by Cranstone (1986; 1989), and much recent work has been completed at Nenthead published as 'grey' literature (Cavanagh & Town 2009a, 2009b, 2009c) culminating in a detailed topographic survey and historical account to inform a conservation plan for the mines (Town 2014).

A large-scale survey project entitled 'The Miner-Farmer Landscapes of the North Pennines AONB', was initiated by English Heritage in 2008. This research is aimed at the lead mining landscapes within parts of the orefield, focusing on Middle Fell, the village of Alston and the area around the Roman fort at Whitley Castle. Some useful data has been published resulting from this work, including an aerial survey and LiDAR study (Oakley et al. 2012) and a survey of an 18km^2 upland area. This survey covered the south-east part of Alston Moor, together with the settlements and historic mining complexes at Garrigill and Nenthead. A total of 2548 sites were identified during the field survey, with the vast majority of the sites being of post-medieval date and directly related to lead mining (Railton and Wooler 2012). Closely associated with this work was a report on the archaeology of the Scordale Valley in Cumbria (Hunt & Ainsworth, 2010).

Work on the bale smelting sites of the North Pennines has been carried out by Fairbairn (1994; 1998; 2007), Smith (2006a), Crossley (1988) and Maxwell (1995). The mining of metals, including lead, has been considered in both the NW and NE Regional Frameworks (Brennand et al. 2006; Petts, with Gerrard 2006).

The history of lead and zinc mining in the Lake District has been explored in journals by the NMRS and local groups including CATMHS. Again, much landscape survey work carried out by various bodies has been produced as unpublished 'grey' reports. Surveys and excavations took place at Barrow Mine, Keswick (Anon 1988), and survey assessments, including lead mining, were undertaken at Thirlmere Estate (Anon 1997; 1998). Greenside in Patterdale has been the subject of several investigations, including Anon (2001a, b), and RCHME (Topping et al. 1992) carried out unpublished survey work at this mine. Force Crag Mine, worked for lead, zinc and barytes, has been the subject of a detailed earthwork survey of the surface landscape (Oswald & Pearson 1999; Oswald et al. 2008).

Archaeological aspects of the Alderley Edge site have been investigated as part of the Alderley Edge Landscape Project organised through Manchester Museum (Timberlake & Prag 2005; Prag 2016). Jackman (1996) gave an account of surface remains at the Snelston Mine in South Derbyshire.

In summary, the majority of archaeological research into the lead, zinc and silver industries has been survey and field recording of surface evidence, including landscape studies, mapping surveys, rapid surveys, air photo transcriptions and some large-scale surveys. Much of this work has been by individuals or groups working in the independent sector, including some work that complements historical studies. The work by professionals in this field has increased over recent years but, as lead mines tend to be located in rural areas, less likely to be affected by development, fieldwork is designed to respond to a different set of threats from those relating, for example, to coal mining. Some focused underground surveys (*see* Section 14) have been undertaken but, as for other metals, the expertise and resources to carry out this work is possessed by only a few people and the results so far are limited. Research excavation, when carried out, has been done largely by those in the independent sector.

Notes

1. Much of the material published by PDMHS (subject to author permission) has made available on the worldwide web www.pdmhs.com/publications.asp
2. Most out of print material published by NMRS from 1960 to 1999 (subject to author permission) has been made available on the worldwide web - www.nmrs.org.uk/
3. For a correction to Bevan - *see* Willies, 2009, 19-32.

8 Tin

Phil Newman

Additional material contributed by Colin Bristow, Adam Sharpe, and Robert Waterhouse

8.1 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 last 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 there in economically viable quantities.

8.1.1 Geology (see Durrance & Laming 1982; Selwood, et al. 1998; Bristow 2004)

Tin (Sn), along with other base metals, is found closely associated with the Southwest peninsula's Carboniferous granite, wherein, like lead described earlier (see Section 7), it was the product of hydrothermal activity. Movement of hot aqueous fluids in the Earth's crust running through fissures or permeating rocks, deposited minerals by means of precipitation to form metaliferous ore bodies. The minerals contained within the solutions solidified at varying temperatures; Cassiterite (tin oxide SnO_2) hardened at the highest temperature, whereas the sulphides such as Chalcopyrite ($CuFeS_2$) the main ore of copper, Galena (lead sulphide PbS) and Blende (zinc sulphide ZnS) cooled at progressively lower temperatures. All hardened into veins, usually known as 'lodes' in Devon and Cornwall. These lodes could be subject to both opencast and underground methods of mining.

In Devon and Cornwall, hydrothermal veins or 'lodes' of tin and copper follow a predominantly ENE trend. Less common are veins oriented ESE known as 'caunter' lodes but it is usual to refer to both these variants as east – west lodes.

In addition to the lode material, the wall rock surrounding the fissures may have become mineralised, referred to by the miners as 'capel'. Where sufficient quantities of ore existed, this phenomenon was called a 'carbona', and although difficult to extract because of the larger quantities of gangue it contained, the material could be worked for a profit when ore prices were favorable and sufficient quantities could be extracted to make the dressing and smelting of them worthwhile.

Within the metamorphosed zones associated with the granite, polymetallic deposits are common, and can contain sulphides, oxides or carbonates of many metals. 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 and copper is arsenic, which was extracted and processed commercially in the 19th and early 20th centuries (see Section 12.2).

Placer or stream deposits make up a significant proportion of all the tin retrieved in Devon and Cornwall, particularly in the medieval and post-medieval periods. These were formed by later weathering of the granite and erosion of hydrothermal veins, which became naturally transported to form alluvial or stream deposits along river terraces and elsewhere. These deposits were of great economic importance due to the lesser effort required for retrieval compared with hard rock mining of the lodes.

8.2 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

Figure 8.1 The earthwork remains of streamworks, shafts and trials at the head of Narrator Brook on Dartmoor. Damian Grady, © Historic England

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 periods, 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 for use in pewter was replaced by that of the tinplate industry. 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 rapidly 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.

8.3 Historical research

Although many 18th- and 19th-century writers offered commentary on aspects of the history of tinworking (e.g. 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 does 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 1999b, 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

Figure 8.2 The upper stone of a crazing mill at Gobbett in Devon. This rare survivor formed one half of a rotary mill used for dressing tin. Untypically, the lower stone also survives at this site, as does evidence for smelting in the form of a mouldstone. © Phil Newman

Figure 8.3 Mortarstones are the main diagnostic artefact associated with early stamping mills. This example with three hollows is all that survives of a mill which was effaced during the construction of Venford Reservoir in Devon. © Phil Newman

for the Tamar Valley (Booker 1968), brought historic tin mining to the attention of a wider public, and 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 (1968a; 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; Corin & Joseph 2013), Wheal Hearle (Joseph 2004), Cape Cornwall (Joseph, 2006), Carclaze (Bristow 2008), Bassett (Buckley 2015) and Great Wheal Vor (Bennett 2015). Many of these works have provided crucial historic context for 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.

8.4 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) (*see also* Section 2.4). 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 resulting from archaeological excavation is still rare, and for ore processing (dressing and smelting) 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 Sharpe *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 the tinworking was taking place has not been identified precisely.

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.

8.5 The archaeological resource

8.5.1 Medieval and post-medieval

Tin deposits exist in two exploitable forms. Lodes, formed through the hydrothermal process, exist as narrow veins of ore-bearing rock running through the country rock. These may occur at 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 had been subject to weathering (see above) 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 (Fig 8.1) 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 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 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 Southwest England, likely to have origins in the prehistoric period. However, the earliest documented streamwork in Devon, *la Drywork*, is of 1240 (Greeves 1981); 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, but the inevitable depletion of the deposits meant that lode sources would ultimately be more productive by the 18th to 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 records exist 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 substantial 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, are usually referred to as

Figure 8.4 Craddock Moor, Minions, Cornwall. Alignments of pits or shallow shafts, evident as earthworks, where early miners worked the backs of the tin outcrops. The area was later worked as part of Phoenix United mines and the engine house of South Wheal Phoenix, now a heritage centre, is visible centre top. Steve Hartgroves, © CHES

'beamworks' and, typically, are of 16th and 17th century date (Greeves 1981); they frequently have sloping sides, and represent the removal of large amounts of overburden. Elsewhere, such as at 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 deep workings known as 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 (Fig 8.4). The term 'lodeback working' has developed in recent usage to describe this method, though the tinners referred to them simply 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

Figure 8.5 Openworks, where shallow tin lodes where worked using an opencast method at Ringleshutts, Devon. Damian Grady, © Historic England

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 because of 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 2003c, 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, including 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 (Fig 8.3), 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, (Fig 8.2) 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 large number of early stamping, crazing and blowing mills have been recorded in Cornwall from documentation, there is less field evidence in that county, and the greatest concentration is on Dartmoor in Devon, where over 50 structures have survived and a further 30 sites are known from either artefact or documentary evidence (Newman 1998a, 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 peat charcoal sourced from Devon; this they were permitted to do 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; 2014b, 21-3).

8.5.2 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. It survives 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 survive, and have been recorded, within woodland such as Steeple Wood near St Ives; Prideaux Wood and the Luxulyan Valley; 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. West Devon examples, recorded by Waterhouse (*unpub*), 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 are evident in Luscombedown Plantation and Hatch Wood, on the same lodes as the huge Gunnislake stockwork (Cornwall), first recorded in 1467; a deep gunnis with multiple shaft-like holes in its roof at Frementor in Blanchdown Wood; and the recent recording of huge beamworks on the line of the Devon Great Consols Main Lode in Greenaven Wood, later worked for copper, but first documented as Willys & Boynabeame tinworks in 1579 (R Waterhouse *pers comm*).

So far, field survey and aerial photographic transcription have dominated the archaeological recording and analysis of tin streamworks, surface lode works and all associated earthworks, including water courses and reservoirs. A 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

Figure 8.6 Disused engine houses associated with tin and copper mines are a characteristic feature of the Cornish industrial landscape. Fewer survive in Devon where deep mines are far less numerous. This example is at Carn Galver, West Penwith. © Phil Newman

at Greena Ball and Mistor (DTRG 1996; 2003; Newman 1998a); Lydford Woods, Stanlake and Hartor Brook (Gerrard 2000); Beckamoor Combe (Newman 2011; DTRG *unpublished*), Crownhill Down (Wilkinson 2010) and lodeback pits at Roos Tor (DTRG *unpublished*). Within the Tamar Valley, an ongoing recording project by Robert Waterhouse to map and record medieval and post-medieval surface and underground tin and copper mining 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. More recently, 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 1996b; 2002a; 2006a; 2006b). A large number of Level 2 surveys and reports of Dartmoor tinworks reside within the NRHE 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

Figure 8.7 The granite cliffs at Cligga Head, North Cornwall, have attracted miners in search of tin for centuries, evident from 'old men's' levels, but the most intense activity here was in the 20th century, when the sett was worked for tin and wolfram.
© CMWHS/Barry Gamble

Mining. This includes areas previously surveyed in detail such as Kit Hill (Herring & Thomas 1990), the Minions Survey (Sharpe 1993c), and 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, though sadly no longer available on the World-wide Web.

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 (A 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).

A range of tinworks has recently (2012-14) been excavated in detail on Crownhill Down, including extensive trenching of a large streamwork, in advance of destruction by the Hemerdon Tungsten mines. This has been the largest archaeological intervention at a site of this type to date and publication is anticipated soon.

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) and Herring (2008). However, modern excavation is limited to the stamping mill at Colliford (Austin et al. 1989), the blowing mill at Upper Merrivale (Greeves 1994) and a possible early smelting site at Brownie Cross in Devon (Taylor et al. 2014).

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*).

8.5.3 The eighteenth to twentieth centuries

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 outcrop 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 radiocarbon 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 (A Sharpe *pers comm*).

Mechanised 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 organisational 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), and Newman (2010a). Certainly, by the time of Carew (1602), in the early 17th century, mining underground was the main 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 comparatively smaller scale, 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 from the tin. Some writers have suggested (e.g. 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 that 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 as well. 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* March 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 often now capped, are sometimes evident by the presence of waste (deads) raised up the shafts and dumped at surface, in 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.

By at least the 17th century, unwatering of tin mines was being undertaken using machines, 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 Marquis 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 a unique example is at Eylesbarrow, where upright stone supports for the rods survive intermittently for over 1.1km (Newman 1999b, 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 used. These often have characteristic field evidence of smaller, rectangular pits adjacent to the wheelpit, which accommodated the winding drum.

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. In the 1920's, they were superseded by electric power as the Grid developed, or as sites were able to produce their

Figure 8.8 Castle Stamps, Porthmoina, West Penwith. Remaining structures of a water-powered stamping mill of the earlier 19th century. The curved-top wall is the splash wall on the west side of the wheelpit. The axle from the wheel to the stamps passed through the squared opening. © Phil Newman

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 at 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) have provided a useful study of their development and diversity. Various surveys have also supplied a body of field data (Sharpe 1986a-c; Nance 1996, 109-22). The significance of steam engine houses to the narrative of 'Cornish Mining' has been thoroughly discussed in the standard literature.

Although the 18th and 19th centuries represent a period of great prosperity in Cornish tin mines, along with those of copper, much mining also occurred after 1900 with around 100 mines being opened or seriously prospected after that date (T Brooks *in lit* Feb 2013). Tin mining and particularly dressing, sources of power and transportation went through enormous changes after 1900. Much of the 'archaeology' in the form of concrete foundations around shafts and dressing floors is from that period.

Dressing

Tin dressing floors may comprise combinations of a large variety of portable and fixed installations but essentially, all fall into the categories of crushing, calcining, classifying and concentrating. Of these processes, some have left more enduring 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, usually referred to as Cornish stamps. Most were powered by waterwheels with batteries of stamps mounted either side, though after 1800 larger batteries of 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; galvanised sheeting was used later, though these rarely survive at all but the most recently abandoned mines, usually saved due to conservation efforts such as at Geevor and Tolgus.

Usually, these sites consist 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) buddles commonly survive as sunken structures or earthworks, as do other forms of tin retrieval system such as Linkenbach tables. 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, the Cot Valley, and various sites in Zennor. A particularly fine surviving example is to be seen at Porthmoina (Fig 8.8), with clear structural evidence (Herring 1996). Seven survive at Eylesbarrow in Devon, dating from the early 1800s (Newman 1999b, 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, usually 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 1987b; 1989b) for example (Fig 9.8) or Phoenix, Levant, and King Edward. At King Edward, a large selection of tin dressing plant and machinery, mostly of late 19th and 20th-century origin, survive thanks to the efforts of volunteers who have restored or reconstructed the dressing mill and other parts of the mine, which is now open as a museum. The mine, its mill and equipment, as well as the efforts of the volunteers, have been recorded by Tony Brooks in a well illustrated account (Brooks 2002).

A major source of archaeological information is contained within the residues of tin dressing which lie

downstream of the dressing mills. Often, these deposits contained sufficient residual tin to make re-working them economically viable, such as the extensive workings at Trevellas Combe and near the old harbour at St Agnes (Stanier 1998, 85-6). The greatest concentrations were in the Red River Valley, where tailings works designed to retrieve this tin, existed almost continuously from the south of Camborne to the sea at Gwithian. Sadly, little earthwork or structural evidence of these now survives.

Calcining

Among the gangue minerals that reside alongside tin and copper, are arsenopyrite (FeAsS), which contains arsenic, and iron pyrites (mispickel - FeS_2); in Devon and Cornwall, the term 'mundic' is often used to refer to both these minerals. They are difficult to separate using conventional gravity methods and their removal was achieved through a burning process, known as calcining.

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 late 18th to 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), and Rose Valley, Morvah. A 19th-century innovation was the Brunton calciner, which contained a water-powered, rotating, calcining floor. Several ruined examples survive in Devon, e.g. Gawton, South-Devon Consols, Owlacombe, Wheal Friendship, and in Cornwall, near-complete examples survive at Tolgus and Geevor, with building shells at Levant, South Hewas, Botallack, Poldice, West Basset Stamps, Gunnislake Clitters.

Apart from the need to clean tin and copper **or**es of their arsenical content, calcination was also used as a means of concentrating arsenic as a marketable by-product, when collected from the inside of the calciner flues (*see* Section 12.3). 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 Pendeen (Joseph 2012, 50). The calciners, labyrinth and stack at Botallack (*see* Section 12.3, Fig 12.4 & 12.5) have been the subject of a detailed survey in advance of recent consolidation works undertaken there (Sharpe 1994).

Figure 8.9 Dressing floors and calciners at Carn Praunter in the Kenidjack valley, St Just, Cornwall. © CMWHS/Barry Gamble

Smelting

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 'blast' from bellows powered by a waterwheel was no longer required.

At some point in the development of reverberatory furnace technology, the two-stage smelting process was devised (consisting of a 'mild' reduction designed to produce tin with a low level of impurities and a second smelt under forcing conditions which produced mainly hardhead Sn/Fe alloy). This probably took place fairly early in the 18th century, when the reverberatory furnace was introduced, and by the late 19th century separate (and quite different) furnaces were being used by some smelters for the two processes. The whole business of hardhead production and subsequent treatment is largely undocumented, although smelters outside of Cornwall and Devon were taking this on in the 19th century. What happened to hardhead produced much earlier by blowing houses is only sketchily documented (R Smith *in lit* Feb 2013)[1].

By the 19th century, most tin smelting was conducted in reverberatory furnaces, although some blowing houses remained until the middle of the 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. Tin smelting in Cornwall and Devon began to be transferred out of the region long before the cessation of tin mining. From the mid-19th century, concentrates were sent to Liverpool, or later exported, or were taken by the expanding UK secondary metals industry.

Movement of materials

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. Tramways 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). Many of these inclines have been recorded by Bodman (2012). 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), include some major railways, plateways and tramways. There is good survival of some early rail systems such as the Poldice Plateway; Redruth and Chasewater Railway; Luxulyan Valley Railway; and Liskeard and Caradon Railway. Some have been subject to archaeological assessment (Gossip 2000; Sharpe 2006; 2007b).

The tin industry also played an important role in the development of seaports around the coast and estuaries of Cornwall and Southwest Devon. On the River Tamar alone, Calstock Quay, New Quay and Morwellham Quay were all serving in the transport of tin copper and other minerals. The Tavistock to Morwellham Canal, with its associated incline, and 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 (Cahill 2000; 2002a; 2002b), and evidence of many transport systems associated with Cornwall's mineral past, have been recorded in the Cornwal World Heritage GIS layers from early map information, including some from the 18th century.

Infrastructure

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 more subtle 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 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 (Cahill 2002c-f; 2004).

8.5.4 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: for tin mines this may be very extensive, and includes 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

Figure 8.10 Geevor was among the last Cornish tin mines to close in 1990, but much of the surface installation has been preserved as a tourist attraction. © Phil Newman

Figure 8.11 Close by Geevor is Levant, where one of the engine houses contains a restored engine, maintained by the National Trust. An important producer of copper, Levant also achieved an impressive output of tin. © Phil Newman

in part to the effort put in for the successful WHS bid. 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 1993c), 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 within it).

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

8.6 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 commercially, 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, in some cases excluding Devon almost completely. A revised historical narrative which encompasses both Cornwall and the substantial documentary legacy of Devonshire in a more objective way, is long overdue. Hopefully, it will include much information gleaned from archaeological research, which for tin mining has come a long way since the dismissive statement by D Bradford Barton that a 'square yard of documents' will 'reveal far more of substance than a square mile of old ruins' (Barton 1968a, 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 to contribute to the accumulation of data on certain topics, many broader research themes remain unexplored. Future research should try to address this imbalance. In Cornwall in particular, a realisation that metal mining is one of the crucial elements of the historic landscape in the county has enabled a great deal of attention to be leveled at it. But beyond the requirements of local government, and conservation, an enthusiasm for tin mining as a subject with broader archaeological research goals is restricted to a relatively small number of independent researchers, professional practitioners and academics.

Note

1. Although these processes lie mainly outside the remit of the Framework, they are mentioned here because of their relevance to the development of the tin industry as a whole.

Acknowledgements

Thanks to Colin Bristow, Adam Sharpe, Robert Waterhouse, Richard Smith and Tony Brooks for additional material, comments and improvements.

9 Copper

Peter Jackson

Additional material and comments contributed by John Barnatt, Peter Claughton, Mike Gill, Phil Newman and Geoff Warrington

9.1 Introduction

Copper was probably mined in Britain as early as 2200BC but, so far, evidence for the earliest workings in England, at Ecton in Staffordshire and Alderley Edge in Cheshire, suggests later origins in the 2nd millennium BC (*see* Section 2). There is currently little evidence for copper extraction in the period following the Bronze Age in England, but it was being mined during the Romano-British period. Similarly, the level of evidence suggests that little extraction of copper occurred in post-Roman Britain as a whole, or in the early medieval period. Although it is known that bells were cast in bronze (see below) in 12th-century Exeter (Blaylock 2000, 4), the source of the copper has not been identified. Attempts to work the metal in Northwest England (centred on Keswick), and at Ecton in Staffordshire, in the early post-medieval period, proved unviable; it was not until the late 17th century that copper was extracted on a large scale in Britain, with mines in Southwest England and Wales at the forefront of production.

9.1.1 Consumption

Since its earliest discovery, copper has been used as a pure metal, or combined with other metals to form alloys. Pure copper is ductile, has high thermal and electrical conductivity, and is resistant to corrosion. The last property makes it an ideal material for the manufacture of water piping and roofing sheets, and as a component of chemical manufacturing plant. Copper bottoming, using massive thin sheets of copper, was used in the 18th and 19th centuries as an anti-fouling measure, to enhance the speed of ships, and to protect their wooden hulls from boring worms in warm, tropical waters. The introduction of copper coinage, in the 18th century, accounted for large quantities of the metal. The property of electrical conductivity enables its use in electric motors, cabling and electronics, which accounts for much 20th-21st century production.

Copper, when alloyed with tin, forms bronze, which is easily cast, hard wearing, and was the first alloy to be used widely in the prehistoric period to fashion weapons and personal ornament. Later, bronze used in the production of cannon, bells, cast sculptures and ship propellers, would create a greater demand for copper. Its hard wearing properties also make it ideal for bearings. The alloy of copper with zinc is brass: although having origins in the Roman period, the late development of techniques to produce zinc as a usable metal (*see* Section 7), explains why brass production in England relied on imports until the 16th century, after which it was adopted for many uses, both as a functional and a decorative material.

9.2 Geology

The geology of copper mineralisation is relatively complex because the orebodies often contain several types of ores. Copper is usually found as sulphide, sulphate and oxidised minerals; it may also occur in complexes, with elements such as arsenic, and in hydroxides. Unlike other non-ferrous metals, the range of copper-bearing minerals present and exploited within England is wide. The most important of the primary minerals are chalcopyrite ($CuFeS_2$), bornite

Figure 9.1 Deposits of chrysocolla - a copper silicate - forming in a water-washed shaft in Engine Vein, at the Alderley Edge complex. © Nigel Dibben

Figure 9.2 General view of Coniston Copper Mines, Cumbria. © James Heaton

or 'peacock ore' (Cu_5FeS_4), chalcocite (Cu_2S), and tennantite ($(CuFe)_{12}As_4S_{13}$). Chalcocite and tennantite are often referred to as 'grey copper ore'. Towards the surface, these minerals have been altered by weathering and oxidation, producing cuprite or 'red copper ore' (Cu_2O), malachite ($Cu_2CO_3(OH)_2$), azurite ($Cu_3(CO_3)_2(OH)_2$), chrysocolla ($CuSi0_3$ - $2H_2O$) and other secondary copper minerals (Read 1962).

Copper ores are, therefore, more complex chemically than the main ores of, for example, tin and lead and contain a lower proportion of the metallic element; a typical ore may only contain 6% copper. They are also less dense and, therefore, harder to separate by gravity methods from the country rock and any gangue minerals. Notwithstanding the variety of ores, the bulk of the production in England has been from chalcopyrite.

9.3 Distribution

Sediment hosted copper deposits are found in the Midlands, principally at Alderley Edge, where they occur in sandstones of Triassic age. In this type of ore body, the copper minerals form a cement between the sandstone grains. The ore bodies are often horizontal or near horizontal, concordant with bedding in the host rocks, and found relatively near to the surface. Vein style deposits are common in parts of England, but were rarely of significance economically, except in Cornwall, Devon and Cumbria. Vein style ore bodies occupy vertical, or near vertical, fissures and can extend to considerable depth, as at Dolcoath in Cornwall (Buckley 2010, 102). In North Devon, on the southern borders of Exmoor, there are lenticular deposits that are confined to particular strata in sedimentary host rocks of Devonian age and probably have a syngenetic origin (Beer & Scrivener 1982, 125-26).

Epigenetic deposits occur in limestone at Ecton in Staffordshire and Middleton Tyas in North Yorkshire. This type of ore body tends to occupy irregular cavities, is usually sub-vertical and often occurs at a shallow depth; however, at Ecton ore was mined to a depth of 300m below the surface by the end of the 18th century (Porter 2004, 92).

Skarn type copper deposits, where the ore occurs in a zone mixed with other rocks and minerals, are rare; one was mined at Belstone, near Okehampton in Devon (Dines 1969, 752).

In Cornwall the occurrence of copper ores is closely associated with that of tin, which may occur at greater depth below the copper deposits. Many copper mines in Cornwall had exhausted their reserves of copper ore by the mid-19th century but continued to raise tin. The surface expression of such mines, including

waste materials and remains associated with dressing, may appear to be that of a tin mine, and evidence of an earlier copper phase may be less obvious.

Copper ores have been noted in many mines in England, but usually not in an economically significant quantity. The occurrences may only be of mineralogical interest but considerable efforts may have been made to search for the ore. Occurrences of copper minerals in the mining districts of England have been documented by Tindle (2008).

9.3.1 Copper mining localities

In England, copper ores have been produced principally in Cheshire, Cornwall, Cumbria, Devon and Staffordshire. The UK contributed more than half the world's output of ore in the early 19th century, with the bulk of the production in that period coming from Southwest England. Production peaked in 1856 (Schmitz 1979) but then fell rapidly, as exhaustion of ore bodies and cheaper imported ore caused the closure of most English copper mines by the end of the 19th century. The last exclusively copper mine to close in England is believed to have been Ramsley in Devon in 1909 (Hamilton Jenkin 1981, 76).

Cornwall and West Devon were the major producing areas from the late 18th to the middle of the 19th century. For example, in the period between 1845 and 1913 Cornwall produced 65% of the UK output and in some years produced over 80% (Burt et al. 1987). Ecton in Staffordshire was another significant producer in the 1750s-80s, although never rivalling the output from Cornwall and other major UK mines, such as Parys Mountain on Anglesey. Devon became a major producer in the second half of the 19th century (Burt et al. 1987) providing up to 50% of the UK output, with a single mine, Devon Great Consols, contributing a significant percentage of that output.

Within Cumbria, copper mining took place in the 16th and 17th centuries around Keswick and Coniston (Figs 9.2 and 9.3). Output at Coniston peaked in the 19th century with annual ore production figures for several years of up to 3000 tons, which represented around 2% of the total UK annual output (Burt et al. 1982, 34).

The existence of mines at Alderley Edge was noted in 1598 and mining activity was documented at various times from the late 16th to the early 20th century (Carlon & Dibben 2012; Warrington 1981a; *forthcoming*). Figures for the output of ore are available only for 1857-1877, when upwards of *c.*168,269 tons was produced (Carlon & Dibben 2012, 150) and for 1914-1918, when output was less significant.

Many mines in England, such as Clive in Shropshire, Snelston in Derbyshire and Doddington in Somerset (Fig 9.4) produced very small quantities of ore and are not typical of the development of the industry. The high value of copper influenced continuing attempts to mine copper ores in England into the mid-20th century, although the output was very small in relation to world production.

Figure 9.3 Underground view of the mid-18th century main shaft (foreground) at Clayton Mine, part of the Ecton complex in Staffordshire. The space behind may have accommodated a horse whim for raising ore in kibbles and water in buckets. The high wall to the rear is part of an 1880s refurbishment and represents the last period of mining activity. © Paul Deakin

9.4 Historical context

(nb Prehistoric copper mining is discussed in Section 2)

Cranstone has remarked that 'Copper mining in the periods from the Iron Age to the 16th century has received little attention' in terms of research (Cranstone 1993a). This certainly reflects the diminutive extent of the industry before the 16th century, compared with other non-ferrous mining, such as tin and lead. Very little historical documentation is known for copper mining in England before the late 16th century, although copper was included in Crown prerogative from the mid-13th century, and frequently included in Crown mining grants (Claughton 2010, 163). There were, however, occasional attempts to work copper bearing-ores during the late medieval period, including the reworking of residues from earlier activity (Rippon et al. 2009, 24-7); it was not until the post-medieval period that there was a sustained attempt to work copper ores in England.

Figure 9. 4 Beech Grove engine house at Doddington Mine, Somerset. Although an insignificant copper mine in terms of output, it does have two early Boulton and Watt engine houses surviving. © Phil Newman

Surviving 16th-century documents featuring aspects of the North Cumbrian mines have provided important historical detail. The Company (or Society) of Mines Royal was mining in Cumbria from 1568 into the early 17th century, under Letters Patent granted by the Crown; these provided the company with monopoly rights to copper and other ores bearing precious metals in certain counties of England and Wales. The enterprise was jointly funded from England and Augsburg (Donald 1994). Similar rights in other counties were taken up by the Company of Mineral and Battery Works (Donald 1961). This Cumbrian copper episode was not a success, as there was no market for the copper produced, which could not compete economically with imports from Sweden (Hammersley 1973); the mines appear to have been sustained by silver production. Some of the mines in Cumbria were revisited after 1693, but with only limited success (Grant 1985).

The episode is often associated with documented inward migration of mining experts from Germany in the late16th century, such as Hochstetter, working around Keswick, and Frosse, who attempted to exploit Cornish sources (Donald 1955, 103). Although much has been made of their impact on the development of mining techniques in the standard historical narrative for this period, their significance and that of the role of the Society of Mines Royal, is questioned by economic historians such as Hammersley (1973, 1-31) and, as yet, completely untested archaeologically.

Richard Carew commented in 1601 that copper could be found in Cornwall 'but with no gain to its searchers' (Carew 1602, C2) and the Company of Mines Royal also searched unsuccessfully for workable copper in Cornwall (Donald 1994). It was not until the last decade of the 17th century that the English copper mining industry developed into a major producer, coincidental with the removal of Crown prerogative and the loss of monopolistic rights to 'Mines Royal' (Claughton 2010, 164). Mines in North Devon, where mining and smelting had previously been attempted in the late Medieval period, grew rapidly by exploiting rich deposits with up to 50% copper metal, but could not be sustained as the mineralisation was of limited lateral extent (Claughton 1991; Dixon 1997). The Cornish mines, and latterly those in West Devon, although not as rich, were capable of far greater production. The export of ore from these mines to South Wales for smelting, led to the establishment of the world's leading copper production centre in and around Swansea (Hughes 2005, 16-55). The re-discovery of large low grade deposits on Anglesey in 1768 (Chaloner 1954), and their subsequent exploitation, together with the establishment of large-scale copper smelting on Merseyside, challenged the dominance of mines in Southwest England and, to a lesser extent, the Swansea smelting interests (Harris 1964).

The rapid growth of copper production at the end of the 17th and through the 18th century attracted the attention of continental engineers, particularly from Sweden, which had been the leading European producer up until that time. Reports by the likes of Cletschers (Liverpool University, Harold Cohen Library, MS 7.1, 21), Kalmeter (Brooke 2001), Angerstein (Berg & Berg 2001) and, to a lesser extent, Svedenstierna (Dellow 1973), have added significantly to our knowledge of the development of copper mining in the United Kingdom during that period.

With significant new discoveries, particularly in West Devon, copper mining in Southwest England recovered to become the dominant copper producing region in the 19th century, with Devon Great Consols, on the River Tamar, becoming the leading world copper producer by mid-century (Goodridge 1964; Stewart 2013). The history of copper mining in Cornwall and West Devon was summarised by Barton (1968b) but has been augmented by Buckley (2005) and, in particular, by the work leading up to the district's inscription on the list of UNESCO World Heritage sites. As yet unpublished, Symons' work (2003) went some way

towards examining the links between copper mining and smelting interests, and their overall effect on the industry in the late 18th and 19th centuries, particularly between Cornwall and South Wales.

There were, however, many other mines across England that contributed to overall production from the last decade of the 17th through to the early years of the 20th century. Unlike the lead industry, for which Burt (1984) has provided an overall assessment, a similar study of British copper mining from the 17th century onwards is still lacking. Harris (1964) went some way towards providing a balanced view of the early development, in relation to the rapid expansion of production from the Parys Mountain mines on Anglesey, but most work has been of a parochial nature, with little reference to a national context.

The mines of Alderley Edge and elsewhere in the sandstones of the Cheshire Basin, which stretch into North Shropshire, have received considerable attention (Dewey & Eastwood 1925; Warrington 1965, 1980a, b; 1981a; 2010; 2012a, b; *forthcoming*; Carlon 1981a, b; Carlon & Dibben 2012). Copper mining specifically in Shropshire is covered by Pearce (1994; 1995; 1997), Warrington (1995) and Shaw (2009). The working of the Ecton Mines, in Staffordshire, in the 18th and 19th centuries has been subject to several detailed studies of historical sources, with attempts being made to link the documentary evidence to the archaeology of the sites (Porter 2004; Robey & Porter 1972; Barnatt 2013). Other minor sources of copper that have been covered include mines at Middleton Tyas near Richmond in North Yorkshire (Raistrick 1936; Hornshaw 1975; Dunham & Wilson 1985, 155-62), in the Weaver Hills and Mixon areas east of Leek in Staffordshire (Robey & Porter 1970, 1971; Porter & Robey 1972a, b; 2000), at Snelston in Derbyshire (Jackman 1996) and Doddington in West Somerset (Hamilton & Lawrence 2008).

The history of copper mining in what is now Cumbria is, to some extent, dominated by the activity of the Mines Royal Company, but later mining attracted interest amongst local historians from a very early date (Postlethwaite 1877); this was followed up in the second half of the 20th century by various authors (e.g. Shaw 1975). The history of some mines has been described in detail - for example Coniston (Holland 1986), Eskdale (Austin 1991), and Goldscope and the Calbeck Fells (Tyler 2005, 2009), although the latter author cites few sources.

The south-western counties of England, Devon and Cornwall, have, as noted above, provided the principal focus for research into the history of copper mining. Barton (1968b) presented an early overview, which has been expanded into North Devon by Dixon (1983;1997) and Claughton (1989; 1991; 1997b), and across West Devon and Cornwall. The focus has been on individual or small groups of mines, such as Devon Great Consols in the Tamar Valley (Goodridge 1964; Stewart 2013), the mines of Caradon Hill (Shambrook 1982) and Dolcoath, which was perhaps Cornwall's premier copper mine, and one that was continually worked in some form from the 16th through to the 20th century (Buckley 2010). The level of archaeological investigation (below) does, on the whole, reflect the domination of the south-west counties although there are notable exceptions, particularly for post-medieval copper mining in what is now Cumbria. Many Cornish mines worked both tin and copper during their lifetimes, and the published histories of such mines as Botallack (Noal 1972), East Pool (Heffer 1985) and Levant (Corin 1992; Corin & Joseph 2013), include both in their narrative.

Figure 9.5 Open gunnis at Ausewell Mine in Devon. Reputed to have Elizabethan origins and recorded as still working for copper by Henric Kalmeter in 1724. © Phil Newman

Copper mining, particularly in the west of England, was of particular significance in the general development of metal mining in Britain. In the 18th century, a combination of new, innovative technologies to enable deeper mining, including water power and steam engines; the use of explosives underground; capitalisation to finance the industry, all served to create a model that would assist in developing deep non-ferrous metal mining elsewhere.

9.5 Technology

9.5.1 Mining

There is no evidence that mining for copper employed methods different to those used for other non-ferrous minerals in England. Early mining was by quarrying the ore using opencast methods, both laterally and vertically, perhaps starting with small trenches and shallow quarries. When the depth below surface became too great for opencast working, mining would commence via small vertical shafts with horizontal levels driven from shaft bottoms. The need for drainage was met by driving sub-horizontal tunnels, known as adits, or by using human or animal power to raise buckets and, when water, atmospheric and steam power became available, by pumping in larger vertical shafts.

The method of drainage was considerably influenced by the topography of the mine's location. A mine on a mountain or undulating moorland could be wholly or partly drained by adits, whereas a mine on level land would require the lifting of water by buckets, barrels or pumps powered by waterwheels and, later, steam engines. Most mines required continuous drainage operations and successful 18th and 19th -century copper mines, particularly in Cornwall and Devon, became dependent upon the development of atmospheric and steam pressure engines. The Cornish mine owners were important early users of this technology and influenced the development of these machines, with the need to work at far greater depths than hitherto. The technology used for hauling ore to the surface followed the same progression and used similar power sources.

Rock breaking underground involved the use of hammers, wedges, hand drills etc. Firesetting was used extensively in copper mines (*see* Section 14), and the earliest use of gunpowder is known to have been at Ecton in Staffordshire (Barnatt 2013). High explosives were developed and used later in the 19th century, when mechanised drilling, powered by compressed air, was also adopted widely.

9.5.2 Ore preparation

Material brought out of a mine usually contained a considerable amount of the host rock, and this, as well as other minerals, had to be separated from the copper ore. Mechanisation of the ore preparation processes came relatively late to copper mining and was never adopted by some small 19th-century operations. The ore was broken or 'ragged' manually using hammers, then hand-picked. In Cornwall particularly, this was the work of women, children and older men unable to work underground (Mayers 2004). Even after the introduction of mechanised crushing in other non-ferrous metal mining operations using water and steam power, some copper ore preparation continued to be carried out by hand; indeed copper ores were often of a sufficient quality to require no further treatment and could be sent directly for smelting following the ragging and picking processes. Water-powered crushing rollers were introduced in around 1806 to deal with more disseminated forms of copper ore (Ferguson 1873), and developed to become the principal method of mechanised crushing, though copper ores were also reduced by stamping mills and, later, by ball mills.

The crushed material was separated in water using gravity methods. Initially, this would be in wood tubs and metal sieves but water and steam power was later applied to sieves shaken in water. Material illustrating the processes used at a major late19th-century copper mine, Devon Great Consols in West Devon, has been published by Stewart (2005).

Ore dressing technology began to develop after 1850 and various experimental methods were also applied. Crushed ore from mines in the sandstones of the Cheshire Basin, at Alderley Edge, and the Clive Mine in North Shropshire, was, after 1857, subject to treatment using hydrochloric acid to leach out the copper, which was then recovered by precipitation using scrap iron (Warrington 1981a; *forthcoming*). Stone leaching tanks used at the Clive Mine until the late 1860s were moved to Bryntail, Montgomeryshire, in mid-Wales where they survive (Bick 1977; Warrington 1980b; Shaw 2009, 248-49). Precipitation was also used at Caradon in Cornwall, and Devon Great Consols in the 1860s (Stewart 2005, 24). In the early 20th century, electrolytic processes were tried at Coniston mine in Cumbria and elsewhere. Flotation processes were developed and applied to copper ores, increasingly in conjunction with the processing of other non-ferrous minerals. There were early flotation mills in Cornwall and Devon that were constructed to process copper and tin ores together, and by the mid-20th century processing plants were built to handle mixed ores containing copper, tin, lead and zinc.

In Cornwall and West Devon particularly, copper ores were calcined or 'roasted' to remove contaminants such as arsenic. By the early 19th century, arsenic was becoming of value in its own right and by the third quarter of the century many mines were making special provision for its recovery (*see* Section 12.3).

9.5.3 Smelting

Some copper smelting is known to have been carried out close to the ore sources, prior to the late 17th century. An example is that at North Molton, Devon (close to the Bampfylde Mine), where copper slags found

Figure 9.6 Copper smelting residues (slag) at Coniston Copper Mines, Bonsor Works in Cumbria. © Richard Shaw

near the mine have been dated to the late15th century (Rippon et al. 2009, 26). However, the introduction of coal to fuel the reverberatory furnace necessary to smelt copper, resulted in a concentration of smelting activity close to the coalfields, predominantly in South Wales (Hughes 2005) but also the Wye Valley, Bristol and Merseyside.

Smelting on the coalfields is outside the remit of this assessment, but we should consider the small smelters found close to the mines from the post-medieval period onwards. A smelter was established at Keswick for the Cumbrian ores in the 16th century and continued working until the early 17th century, using locally prepared charcoal along with coal from the West Cumberland coalfield for ancillary processes.

There is reference to a 'Smelting Milne' at Alderley Edge in 1696, and to the existence of smelting works there in the early 18th and the early 19th centuries; large quantities of 'scoriæ or slagg' were noted in 1810 (Warrington 1981; *forthcoming*). Charles Roe and Co., later to become the Macclesfield Copper Company, constructed a copper smelting works at Macclesfield in the mid-18th century (Bentley Smith 2005, 205). The Duke of Devonshire was smelting copper at Whiston, close to his Ecton mines (Porter 2004, 124-45) in the late 18th century. For a short period copper was smelted at Hayle in Cornwall by the Cornish Copper Company, using coal shipped from South Wales during the late 18th and early 19th centuries (Pascoe 1981; Ferguson 1996, 104-8).

9.5.4 Movement of materials

Prior to the early19th century, most mines relied on pack horses to carry ore to the nearest coastal or river port for shipment to the smelters, and coastal shipping was a key element in the movement of copper ores. Statistical evidence for coastal transport, extracted primarily from the Exchequer portbooks, has been examined in some cases (*for example* Hussey 2000, 116-19), but the pack horse is a poorly researched (and probably poorly documented) form of transport.

Early railways and plateways were constructed in Cornwall and Devon (Barton 1964) in order to link the mines to small shipping ports (*see* Section 8). These routes provided the means for transporting copper concentrates to the seaports, necessary to provide access to the South Wales smelters, and for importing timber and coal for the mine operations. The Portreath Tramroad, the Redruth and Chasewater railway (Barton 1966), and others to Callington (Crombleholme et al. 1967) and Caradon (Tolson et al. 1974), were examples of railways constructed to serve copper mines. Some of the shipping ports were built and developed as part of the transport link from line to smelter and worked in conjunction with the tin mining industry.

The need to move copper, along with lead and tin, lay behind the construction of the Tavistock Canal in Devon, serving the mines in the upper Tamar valley and West Devon and as far east as Wheal Friendship at Mary Tavy. The canal, completed in 1817, and a series of inclines, delivered the ores to Morwhellham Quay on the banks of the River Tamar, from where sea-going ships could transport the ores. Among the mines using this route, after 1844, was Devon Great Consols (Booker 1974, 31). Growth of the copper industry in the Tamar valley during the mid-19th century resulted in an expansion of port facilities along the Tamar at Newquay and Gawton, and at existing quays such as Calstock on the Cornish side of the river.

Hayle Harbour in western Cornwall, and the town that surrounds it, was created and evolved largely around the Cornish Copper Company, which began smelting copper there in the 1750s. Quays were built in Hayle's natural harbour for the shipment of coal. Allied industries, such as Harvey's foundry, built up their bases from Hayle through the use of the port (Todd & Laws 1972, 86-102).

9.6 Archaeology

The pattern for the archaeological investigation of copper mining and associated processes across England is uneven. As stated above, it is dominated by work carried out in West Devon and Cornwall, and although much research was commissioned in connection with the proposal for World Heritage status, it also reflects the position of those counties as the major copper producing region in England. Some of the investigations are assessments of the archaeological assets, as with Devon Great Consols and other Tamar Valley mines (Buck 1998, 2001a, b), but others are comprehensive

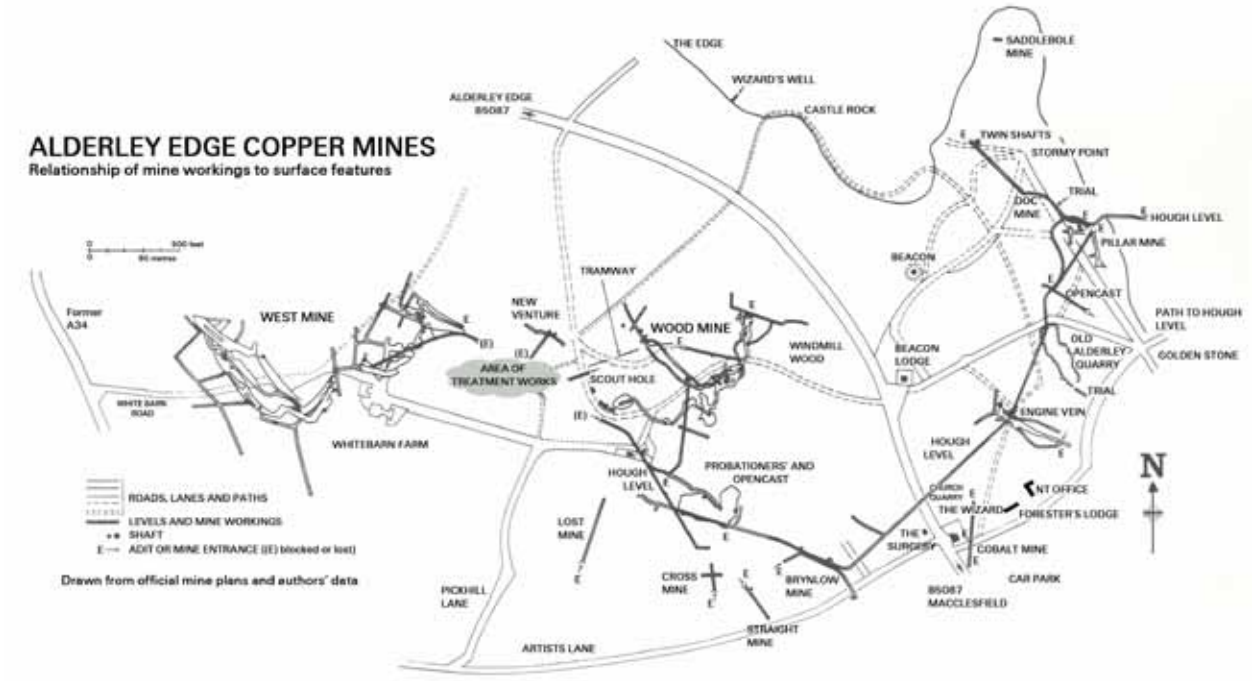

Figure 9. 7 Map showing underground workings at Alderley Edge Copper Mines. From Carlon and Dibben 2012 © Copyright.

surveys. Copper mining on and around Caradon Hill in East Cornwall, centred on Minions, was a major part of one of the first comprehensive landscape surveys carried out by the Cornwall Archaeological Unit, now part of Cornwall Historic Environment Services (CHES), and included detailed record of many surface features (Sharpe 1993c).

In addition to those mentioned above, copper mines in Cornwall and West Devon that have been the subject of archaeological investigation at some level, include Tresavean (Sharpe 1989), Dolcoath (Sharpe 1993b; Buck 2001c), Buller (Lawson-Jones 1998), United (Reynolds 2000), Bedford United (Buck 2003), West Basset (Palmer & Neaverson 1987; Sharpe 2007a, b) and Consolidated (Sharpe 2009), but this list is by no means exhaustive. The Tamar valley has an active industrial archaeological group (TVIA), which, as part of its investigations, has researched copper mines around Morwellham and Tavistock Canal (Waterhouse 2012). Some of their findings are published on the web[1] and a publication is imminent.

In Devon, east of the Tamar Valley and outside the area defined in the World Heritage inscription, the mines on the peripheries of Dartmoor have been surveyed in some detail at surface, primarily by the RCHME (later English Heritage) survey team formerly based in Exeter; these include Ausewell Wood Mine (Newman 1998b; 2004b), Druid Mine (Newman 2003a), Brookwood and Wheal Emma (Newman 2005, 2006c). Ausewell Wood (Fig 9.5) has also been subject to geochemical (Carey 2000) and geophysical (Dean & Faxon 2000) surveys. The Bampfylde Mine at North Molton was also the subject of survey by the RCHME and was interpreted in *The Field Archaeology of Exmoor* (Riley & Wilson-North 2001, 148-51). Evidence for late medieval smelting has been identified at Bampfylde (Rippon et al. 2009, 26), although the site of the furnaces has not been located. At Doddington, in West Somerset, the history of which was covered by Hamilton & Lawrence (2008), the surviving surface features, including two ruined Boulton and Watt engine houses (Fig 9.4), were re-surveyed by English Heritage in 2003 (Newman 2003b).

Little, if any, archaeological work appears to have been carried out on the small copper mines in West Shropshire but those in the north of the county, on the rim of the Cheshire Basin, have been the subject of limited investigation (Ove Arup 1993). The accessible workings of most of the mines in the county have been surveyed or described by the Shropshire Caving and Mining Club[2]. Extensive investigation at Alderley, has focused primarily on the Roman and prehistoric workings, but has extended to features associated with later activity (Timberlake & Prag 2005; Prag 2016). Accessible workings of all periods have been surveyed by Paxton (1953), Pickin (1974), Warrington and others (Warrington 1965), often following clearance work by Derbyshire Caving Club members (*see* Carlon & Dibben 2012).

The Ecton mines in Staffordshire have been subject to detailed archaeological investigation by John Barnatt and colleagues, who have evaluated the subterranean and surface archaeology, in combination with a reassessment

of the documentary evidence (Barnatt 2002b, 2013; Barnatt et al. 1997). Again there is significant interest in the evidence for prehistoric activity (see Section 2) but the medieval and later workings have also been well served, and much new information is now available on the extent of the mines and its dating as a result.

The copper mines at Middleton Tyas, in North Yorkshire, have not been subjected to any archaeological investigation but key surface features were identified in Hornshaw's detailed history of the site (Hornshaw 1975, Map 3).

In the Northwest, in what is now Cumbria, copper mining has been a focus of research since at least the 1980s, an early example of which was the survey of the dressing floors and other remains in Coppermines Valley, Coniston (Middleton 1985). Other surface features around this mine have, subsequently, been investigated in some detail, including the Paddy End dressing floors (Anon 2007) and the Greenburn Mine (Oswald et al. 2001); conservation management plans have been prepared for two sites, Coniston Copper Mines (Anon 2010a) and Penny Rigg Mill (Anon 2010b), and potential post-medieval workings close to Leverswater were the focus of investigations by *Time Team* (*CAT* **109**, 7-18). [3]

In the Caldbeck Fells, the Silvergill and Roughtengill mines, which produced some copper in addition to lead and silver, were surveyed at surface by English Heritage (Jecock et al. 2001), producing evidence for working from the post-medieval period through to the 19th century. Subterranean investigations, focusing primarily on the former period, are ongoing but some work has been reported by Allison & Murphy (2010). Most, if not all, of the accessible subterranean workings mentioned above have been explored and surveyed by mine exploration groups in the Lake District. Much of that material is archived by the Cumbria Amenity Trust Mining History Society.[4]

A few smaller mines have also been subject to some investigation, for example Potts Valley (Anon 2004) and Browns Crag (Anon 1997). It is also understood that some archaeological investigation has been carried out at surface and underground on the mines in the Newland Valley, particularly Goldscope, which is known to have been worked in the 16th century, but no records are available. The Lake District National Park Authority (LDNPA) *Reflections of History* programme has recently (2013) commissioned investigation and mapping of copper mining and processing features at the Greenhead Mine. Ten buddle sites, a leat associated with the stamps mill, and at least one structure, all dating from 16th-century activity, have been identified; publication is pending.

Figure 9. 8 The extensive, well-preserved and much studied surface remains of tin stamps and dressing floors at West Wheal Basset in Cornwall, date from the 1870s. However, this, together with other mines in the Camborne district had been an important producer of copper earlier in the 19th century, for which surface archaeology is less well studied. Steve Hartgroves, © Cornwall HER

Notes and Internet sources

1. www.tvia.org.uk
2. www.shropshirecmc.org.uk/sites
3. The Coniston and Tilberthwaite are now (2015) the subject of an HLF funded programme of investigation and conservation to be carried out by the Lake District NPA.
4. CATMHS www.catmhs.org.uk/archive.php

10 Gold

Peter Claughton

10.1 Introduction

Gold recovery is a minor aspect of the extractive industries in England. Unlike Wales and Scotland, there has been no sustained production in modern times, nor are there identifiable prehistoric, Roman or medieval extraction sites. There are, nevertheless, some surviving archaeological features and the potential for further discoveries which can be related to gold extraction.

The geology of gold mineralisation in Britain has been studied in some depth in recent years. Potential sources having no historical exploitation have been identified, and sources worked from at least the period of Roman occupation are now better understood (Cooper 1998; BGS nd). Most, if not all, the gold mineralisation in England is confined to the older rocks and those associated with volcanic activity in north-west and south-west parts of the country. Those rocks, however, have not been as productive as similar rocks in Scotland and Wales. Of over 3500kg of gold recorded as being recovered in Britain between 1860 and 1909, 90% came from the Dolgellau gold belt in North Wales, whilst the remainder came from the Ogofau Mine in Carmarthenshire and the Helmsdale area of northern Scotland (BGS nd, 1). What production there was for England, and it has never been officially quantified, came almost exclusively from Devon and Cornwall prior to 1860. In the former case it was found in copper-iron deposits, fissure fillings with possible syngenetic origin, in Devonian rocks at North Molton (Cameron & Bland 1994, 4-5; Camm 1995, 87-88). Gold has also been found in alluvial tin-bearing deposits associated with the granite emplacement from Dartmoor to Bodmin Moor and westwards into the far west of Cornwall (BGS nd, 4). Dines makes the claim that small grains of gold had been recovered in practically every alluvial deposit in Devon and Cornwall, but that it has never been systematically recovered (Dines 1956, 30-1). In most cases, the alluvial deposits were the result of erosion of epigenetic deposits in the granite and the adjoining metamorphosed rocks, but there is evidence to suggest that some deposits in North Cornwall originated from pre-granite mineralisation; for example at and around the Treore mine near Port Isaac (Scrivener & Shepherd 1998, 145; Camm 1995, 53-59). The Treore stream was worked, albeit on a small scale, for gold and reported on by Edwards in the *Mining Journal* (1916, CXII, 103). It is, perhaps, the only record for historic working exclusively for gold in Cornwall (S Camm *pers comm*). For modern prospecting and gold-panning activity across Britain, see Callender (1990).

10.2 Historical Context

Whilst there is no specific evidence, it is very probable that gold has been worked from alluvial deposits in Southwest England since before the period of Roman occupation. Clear evidence does not emerge until the late medieval period, when the right to work gold-bearing deposits was regularly recited in grants made by the English Crown from the early 14th century onwards and there is specific reference to its

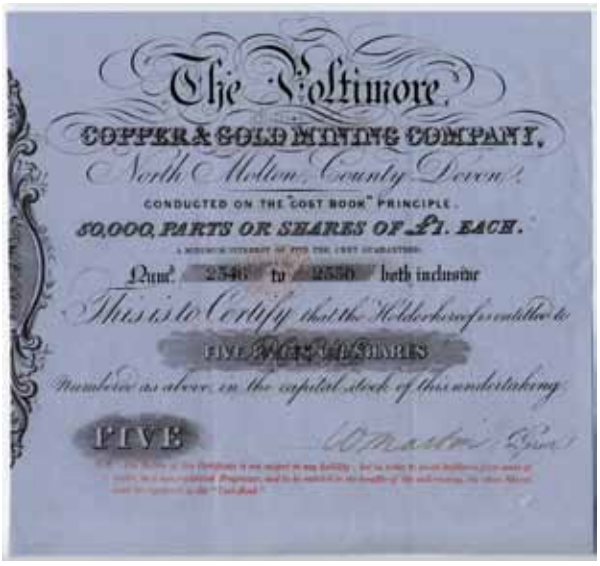
The Poltimore
COPPER & GOLD MINING COMPANY,
North Molton County Devon
CONDUCTED ON THE "COST BOOK" PRINCIPLE.
50,000 PARTS OR SHARES OF £1. EACH.
Num. 2546 to 2550 both inclusive
This is to Certify that the Holder hereof is entitled to
FIVE
Numbered as above, in the capital Stock of this undertaking
FIVE

Figure 10.1 Share certificate of the Poltimore Copper and Gold Mining Company, undated but c.1854. One of the North Molton mining companies associated with exaggerated claims about the occurrence of gold in the area. © Phil Newman collection

occurrence in tin workings. In 1325, 22 pennyweight of gold was recovered from mines in Devon (TNA: PRO, E101/262/2), and in 1377 Henry de Burton produced gold 'found in a river in Devenshire (sic)', and he was then tasked with searching out further deposits (*Cal. Close R.*, Ric. II, **1**, 90-91). This gold found was probably the product of tin streaming activity, as described in Cornwall in later periods (Buckley 1994, 101-13), but there were no subsequent references to payments in gold into the Exchequer. The tinners were, no doubt, quick to conceal the gold and only obliged to pay coinage on their tin production. Carew reported in 1602, that tinners would often find gold within the tin ore, which they would keep in quills and sell to goldsmiths (Carew 1602), and De La Beche confirms that this practice was still current in the 1830s when grains of gold were taken to Truro to make wedding rings and small items of jewellery (De La Beche 1839, 613). In the period 1445 to 1451, returns for 'St Tether', probably the parish of St Clether on the north-east border of Bodmin Moor in East Cornwall, recorded the production of silver worth three marks (£2) but state that no gold was found (BL Add MSS 24513, f95).

There is a suggestion that gold might have been recovered from primary deposits when gold/silver/copper deposits attracted Crown interest in Devon in the 1260s: a discovery which led to the Crown asserting its right of prerogative. The location, at 'La Hole', is undefined, but probably lay on the southern borders of Exmoor in the area of Molland, where copper deposits do carry some silver and were considered to be gold bearing in the mid-19th century (Rippon et al. 2009, 28; Claughton 1997c).

The presence of gold in the copper deposits at the Bampfylde Mine, at North Molton in North Devon, was known from at least the late 18th century, and has been confirmed in recent geological investigations (Cameron & Bland 1994). Although gold is not referred to specifically in the late medieval period, the mine was always identified as the 'king's mine' (Rippon et al. 2009, 25-26). Polwhele (1797, 69), quoting Chapple, states that gold had been found in a rich copper mine in the parish of North Molton. This can be identified with the site now known as the Bampfylde Mine (Claughton 1997c, 2-3), but it was not until the 1840s that the mine was being worked specifically for gold, in addition to copper, when the Prince Albert Mining Company was formed and one of its adventurers made approaches to the Crown for rights to work gold (CRO DDFS 3/134 and 135; Claughton 1997c, 2-3 for further details). There was also, in the period 1843-49, a further application to the Crown to work gold 'at South Moulton (sic)' (TNA: PRO CRES 2/207). It was, nevertheless, the publicity and the techniques associated with the discovery of gold in California in 1848, which appear to have pushed the interest in gold at North Molton to the fore, and stimulated its working on a larger scale than hitherto.

There is scant evidence for dedicated gold extraction outside Southwest England. Calvert (1853, 102-07) makes vague references to gold found in the north-west, in the counties of Westmorland and Cumberland, for which there is perhaps some credibility given the identification of gold-bearing polymetallic mineralisation in the area (BGS nd, 3; Cameron et al. 1993, 15). Calvert's other references to gold extraction in other counties of England, except Devon and Cornwall, are largely based on the erroneous assumption that, if gold was cited in a Crown mineral grant, it was the object of the search, which was seldom the case. The extraction of gold in unlikely locations such as Essex (Calvert 1853, 109-10, citing amongst other Pettus, *Fodinae Regales*) is, however, based on local myth rather than substantive evidence for working.

Following on the discovery of gold in California and Southeastern Australia, in 1848 and 1851 respectively, there were numerous futile attempts to work gold in England. The Lathkill Gold Mine, in Derbyshire being one such example (Grigor-Taylor 1972). Publications, such as that by Calvert in 1853, fuelled the search, and the presence of gold in many streams, albeit in uneconomic quantities, only abetted those searches; references to working and, perhaps, even physical evidence for attempted working, might therefore be found in counties outside the North West and Southwest England.

10.3 Technology and techniques

The working techniques for gold are in many respects no different from other non-ferrous metal ores, be they primary or alluvial deposits. Although gold was recovered from alluvial tin workings in Devon and Cornwall, it is unlikely that the streamworks, as described in the assessment for tin (*see* Section 8.5.1), would have distinct features related to the gold recovery. On the other hand, where gold was the primary metal recovered from alluvial workings, in areas remote from the tin bearing rocks, distinct 'streaming' features might be identified. This is the case in Southwest Scotland where those features are found at Wanlockhead, which has a history of alluvial gold working from at least the post-medieval period (Pickin 2004).

Treatment of gold-bearing deposits once mined did call for specialist techniques. Gravity separation might suffice in some cases but, where the gold was combined with other minerals, or was particularly fine, extraction through crushing and amalgamation (using the affinity of gold to mercury) was necessary. In the

Figure 10.2 No Berdan gold amalgamation pans survive in England but two Britten pans, a later development on the same principle, have been preserved, albeit not in situ, at Coed-y-Brenin, Merionethshire. © Peter Claughton

1850s new amalgamation techniques were introduced into Britain, which combined ore crushing/grinding with amalgamation using heavy iron rollers, or spheres rotating within an iron vessel or 'pan'. The most common of these were the Berdan and the Perkes machines, and the former was trialed extensively across Southwest England. After experimentation with other methods, a Perkes machine was installed at the Britannia Mine, North Molton, and a Berdan machine at the nearby Bampfylde Mine (then known as the Poltimore), in 1854. Unfortunately, the rich gold assays had been highlighted and poor returns ignored, and the bulk treatment of ores from both mines failed to recover any gold (Claughton 1997c). The Berdan machine, and later developments of the technique, were, however, used successfully on gold mines in Wales and elsewhere, and a pair of Britten pans (Fig 10.2) recovered from the Bedd-y-coedwr (Marina) Mine survives at Coed y Brenin in Merioneth, North Wales (Morrison 1975, 18-21).

10.4 Archaeological research

Very little investigation has been carried out on the archaeology of gold working in England, although the situation is much better in both Wales and Scotland. The Bampfylde Mine at North Molton was surveyed by the Royal Commission on Historic Monuments in England as part of Exmoor National Park's West Exmoor Project (Wilson-North 1996), and was published, along with an interpretation, in *The Field Archaeology of Exmoor* (Riley & Wilson-North 2001, 150). Features, such as the Berdan machine house, associated with gold working can be compared with similar features investigated elsewhere, for example the structures associated with a Britten pan installation at Cefn-coch in Merioneth[1]. No alluvial workings specifically for gold have been identified in England, but those found in Southwest Scotland (Pickin 2004) provide examples for informing any future searches. The detailed work carried out on late prehistoric, Roman and modern gold working (the Ogofau Mine) at Dolaucothi in Carmarthenshire also provides data which might inform investigations in England (Ancel et al. 2000).

Acknowledgements

Thanks to Ron Callender, for constructive comments on the draft text and the loan of his copy of Calvert. Also to Dave Williams, Phil Newman and Simon Camm.

Internet sources

1. www.coflein.gov.uk/en/site/33962/details/cefn+coch+mine+%28gold%29%3bnew+california/[accessed 18 August 2012]

11 Gangue Minerals and Pigment Earths

Michael Shaw

Additional material contributed by Peter Claughton

11.1 Introduction

This paper deals with two separate groups of substances: minerals, which at sometime have been considered to be gangue, and pigment earths.

The archaeology of the extraction of substances grouped together because they have at sometime been considered not only waste but very inconvenient waste, is not without problems, as a concept; not least is what to include both in terms of substances and of sites.

The Durham Regional Research Framework[1] has this telling statement which provides a realistic starting point for gangue minerals:

> the remains associated with those industries (Barytes & Witherite) still stand but have been largely ignored in favour of the structures associated with the lead industry in the same area, which mainly date to the eighteenth and nineteenth centuries.

The fact that recent mines have required planning consent, and that consent has included conditions, which required the land to be returned as far as possible to its pre-mining condition, has cut off almost totally any significant archaeology for post-war mines, mills etc.

For the purposes of this report, gangue is defined as being substances in a vein associated with the ore sought, which had no current value, and were either raised and disposed of, or sorted below ground and left as deads. The definition of gangue is not fixed, leaving considerable debate as to whether, for instance, the material need be brought to the surface to be gangue, or whether the by-products of ore preparation should be so considered. Pigment substances have sometimes been gangue but in many cases have also been the subject of primary extraction, sometimes for millennia.

Of the substances which could be classified as gangue, this report deals with barytes, fluorspar and calcite, and of the pigments graphite, carbon black, ochre, raddle, umber and wad. It should be noted that in some places ochre is called raddle, and the word wad, whilst generally being used for a black manganese-rich clay, is used to refer to graphite in the Lake District (at least). Malachite, azurite, pyromorphite and chalk (as whiting and hearthstone) have also been extracted as pigments, the archaeology of these substances being covered elsewhere in this report (*see* Section 2).

For the purposes of this report, sites can be divided into six groups with varying potential:

1. tips at mines which did not ever work or recover gangue
2. mines which recovered or later worked gangue
3. mines opened to work what had been gangue
4. mines primarily extracting decorative substances
5. processing sites
6. transport infrastructure.

Of the above categories the first two may well have no archaeology specific to their gangue. Sites for categories three, five and six provide the bulk of the information. From category four, a few mines are still working (Rogerley, County Durham for fluorspar crystals, caverns at Castleton for Blue John and Clearwell for ochres) and perhaps creating archaeology, though probably destroying more.

With these problems and limitations in mind, what follows naturally focuses more on the potential of orefields and individual mining sites to possess archaeological remains specific to the mining or production of gangue minerals and pigment earths, rather than providing a discourse on archaeological achievements which, as yet, are few.

11.2 Historical context and consumption

11.2.1 Barytes and Witherite

Consumption

Barytes, barite, barium sulphate, $BaSO_4$, usually a whitish, dense, flaky earth or crystalline material, known to the miners as cawk, heavy spar, brites and many variations, was almost always treated as gangue until the second half of the 19th century when uses for the material increased.

Figure 11.1 A 1929 view of Cothercott Barytes Mine, Shropshire. A typical early-20th century small gangue mineral plant towards the end of its life. © BGS

Figure 11.2 A 2004 view from a similar vantage point showing how industry can disappear after 60 years. © Mike Shaw

The principal properties of barytes to give it economic value are its density and inertness, and the majority of its use was in a comminuted form. Its inert properties made it useful as a filler in paint, paper, etc, and later in plastics. Its density made it particularly suited for use as an oil-well drilling mud. This use has provided the overwhelming demand for the material since the Second World War. A combination of these properties enables barytes to provide a significant degree of protection from radiation, leading to its use either as a shield, as happened after the accident at the Windscale nuclear plant in 1957, or as a component of bricks or concrete in hospital and laboratory construction. In its purified form, it is the opaque matter ingested as a barium meal for medical use.

Chemical grade barytes (and witherite) was, and still is, used as a feedstock for the production of a substantial number of useful chemicals. Witherite is barium carbonate: it was principally used to produce the same barium chemicals as barytes, but it was cheaper to process, because it has the advantages of a greater barium content and is more reactive. Various pigments can be made from the barium chemicals and precipitated barium sulphate is a significant white pigment.

Barytes also has a limited profile as a decorative material: lumps from Raygill Mine were used in Victorian rockeries, and a brown and white banded psuedo-stalagmitic form was mined at Arbor Low, Derbyshire and polished and sold as 'oakstone'.

Production

Limited mining took place in England until the late 1850s when rather more coherent production started. Production increased slowly until the First World War, when the cessation of imports from Germany allowed the increase to accelerate. During the interwar years, production increased further to reach a peak in the 1940s, but thereafter imports gradually drove levels down. Shropshire stopped producing in 1948, the West Country followed a decade later and work in the North Pennines had halted by 1999. This left a small level of production from Cavendish Mill in Derbyshire as a by-product from fluorspar mining and milling. Large deposits found in Scotland have reduced the need for imports, and current needs are met mainly by Foss Mine, with large reserves (probably greater than the total mined in the British Isles to date) at Duntanlich.

For many years the UK was the world's only producer of witherite; when the last mine closed in 1969 world production ceased for a number of years with production subsequently restarting in China.

11.2.2 Fluorspar

Consumption

Fluorspar is the commercial term for the mineral fluorite, calcium fluoride, CaF_2. It can be either massive or crystalline. The crystals are generally isometric, often twinned, though more complex forms occur. It exists in a variety of colours commonly purple, blue, green, yellow and colourless; pink, red, white, brown and black are also known, colour banding is common. Apart from its industrial uses, this range of colour and pattern has made the mineral, despite its relative softness (Mohs hardness 4), a semi-precious stone. In the form known as 'Blue John' it has status as a decorative stone.

Industrially, three grades are recognised: metallurgical grade fluorite has the most widespread use as a flux in several metal industries. Most significantly, in steel making, it reduces the melting point of the raw material and aids the removal of impurities. Ceramic grade is used in the production of certain types of glass and enamels, while acid grade is used to make hydrofluoric

acid from which is produced an important range of fluorine compounds.

A further use, not quite in any of the previous categories, is to replace glass in some specialist telescope and camera lenses. Also, it has some very special properties in relation to ultraviolet light having a unique transparency at 157nm wavelength allowing fluorspar lenses to be used for fluorescence microscopy.[2]

Production

All UK production had ceased during the drafting of this section of the Framework. However, following closure in 2010, at the time of going to press in January 2016, Cavendish Mill is again operational being worked by British Fluorspar, who operate the mill with supplies from their own and tributer opencast working in the Peak District. Only acid grade material is produced (with by-products in the form of barytes, galena and limestone aggregate). The two opencasts are at Longstone Edge and Tearsall.[3] Commercial mining in the northern Pennines (principally in Weardale) ceased in 1999. Mining is now limited to decorative material, with production of small quantities of Blue John from the caverns around Castleton in Derbyshire, and well-crystallised specimens for collectors from Rogerley Mine, County Durham, which was reopened for the purpose in 1972.[4]

Around Castleton in Derbyshire, mining for Blue John began by the mid 18th century (Ford 2000, 56). Fluorspar's use as a flux is known from at least the 16th century, and metallurgical grade production is noted in England from the last quarter of the 18th century, from Critchman (Knowles) Mine, Masson Hill, Matlock; from there it was used in lead smelting at Ecton mine, Staffordshire (PDMHS *Newsletter* 138, April 2011). However, national output remained small throughout the 19th century, and was mainly a by-product of lead, tin and copper mining in Cornwall and Devon (Cranstone 1993b, 17). Production rose from about 5000 tons in the whole of the 19th century to 65,000 tons in 1908 with the development of the steel industry; but prices fell over that same period as substantial reserves were exploited (Burt 1984). By the late 1980s production was about 340,000 tons per annum about half of which was from tributers (Bramley 1991).

Figure 11.3 Bowl made from Derbyshire Blue John. Located in Castleton Visitor Centre, Derbyshire. © Open source

11.2.3 Calcite

Consumption

Calcite is a crystallised form of calcium carbonate, $CaCO_3$. The crystals are trigonal-rhombohedral though they show a considerable variety of habits. Calcite is generally clear or white, but impurities can colour it. Also known as light spar, calspar and calc-spar, the last is generally used to describe the opaque material. It is the principal constituent of limestone and, when metamorphosed, of marble. It can be used for any industrial/chemical use in place of limestone, but as gangue its principal uses have been decorative, both as a range of crystals and crushed as spar chippings or sand in pebbledash, stucco, terrazzo, road surfacing and road 'white lines'.

Production

Production began in the mid-19th century, though maximum production was not reached until well into the 20th. Mining ceased in the 1970s though open-working continues. It is estimated that around 1,000,000 tons have been extracted to date (Ford 2002). From the 1960s to the 1980s production was about 20,000 tpa, half from Derbyshire, but by the end of the century it was down to about 14,000 tpa (Ford 2002), all from that county.

11.2.4 Pigments

Consumption

The uses of pigments are fairly self explanatory, though many of these substances had other uses. Often, material which could have been used as a pigment has been mined for its metal content.

Production

Graphite is an allotrope of carbon, a black semi-metal, also known as plumbago, black-lead or wad (not to be confused with the manganese oxide ore, also known as wad, see below). The mineral was known to the monks of Furness Abbey, who are reported to have used it to mark their sheep (Lax & Maxwell 1998), and to rule guide lines in documents[5]. By the late 16th century it was certainly in use as a drawing material and probably for rust proofing iron (grate polish etc) (Camden 1610).

The only mine to work the mineral in England, was at Seathwaite; it passed through many hands including, in the early 17th century, the Hochstetter brothers, as a private venture rather than as part of their Mines Royal activity. The most significant uses during the 18th century were for moulds for cannon balls and other iron munitions, crucibles and lubrication for ship's rigging. These uses gave the material immense value, £3,500 a ton being noted *c.*1800[5]. The material led to the development of the Keswick pencil industry in the late 18th century, with locally mined graphite being used for the best quality pencils until stocks were exhausted before the First World war, mining having ceased *c.*1891. Graphite occurs as pipes, lumps, nodules, sops or bellies up to 1m by 3m, often following quartz strings.

Carbon Black is a carbon-rich black mineral peculiar to North Devon - this was extracted from anthracitic clay deposits in a seam found in association with the anthracite seams running east and west in the Culm Measures either side of the River Torridge at Bideford (Langton 1928). Total production figures are unknown but the material was used extensively for the preparation of paints for the Royal Navy in the 18th and 19th centuries, and working did not cease until the 1960s.

Ochre is an 'earthy material of no fixed composition' … 'mostly impure goethite (limonite) mixed with clays' (Ford 2003), with a significant iron oxide (Fe_2O_3) content and a range of colours. Red and purple ochres contain anhydrous iron oxide, brown, partially hydrated iron oxide, and yellow hydrated iron oxide. It has been extracted for millennia (*see* Section 2.2), and is among the earliest pigments used by man; its mining and sale continue. Ochre is levigated, i.e. stirred in water to leave the pigment in suspension, this is then dried at low temperature and packed for use (Ford 2003). It is a common material in coal measures, at times being extracted for sale. Few statistics are available, but national production between 1919 and 1939 was around 9,000 tons per annum, with Derbyshire contributing 5% of that, mainly from coal mines (Ford 2003).

The mining of ochre and other iron-based pigments was a significant extractive industry in the Bristol and Mendip (Somerset) area, sometimes linked to hematite iron ore extraction, and was studied in some detail in the 1980s (Clarke et al. 2012). Many of the abandoned workings were explored and mapped along with the surviving surface features, and the field evidence was linked to the documented history of working.

Raddle is also an iron-based pigment produced from fine, red haematite (Fe_2O_3). It exists either in clay as ochre when it is levigated, or in crystalline form when ground, and used either as red pigment or as jeweller's rouge. It can be found with ochre, and the name raddle is sometimes used for red ochre. There are no production statistics available.

Figure 11.4 One of several surviving boundary stones surrounding the graphite (or wad) mines at Seathwaite in Borrowdale, Cumbria and inscribed with 'John Shepard Esquire 1732'. © John Mallet, National Trust

Redding is an alternative term for ochre, used in the Bristol/Mendip area.

Umber is not as widespread as ochre though related, being a clay based material but having a higher manganese content. It is a sufficiently well defined substance to have a formula, $Fe_2O_3 + MnO_2 + H_2O + Si + Al_2O_3$. Its dark brown colour depends on its manganese content and on its processing, with heat treated (burnt) umber being more intense. There are few production statistics available, but Derbyshire possibly extracted about 10,000 tons of wad and umber from the late 18th to the early 20th centuries (Ford 2001b). At the Ashburton Umber Works in Devon, over 7,500 tons were produced between 1873 and 1883 by two separate companies (Hamilton Jenkin 1981, 111).

Wad is an earthy black ore, with a higher manganese content than umber. It has no specific chemical composition but is composed mainly of hydrated manganese oxides. It can be used as a dark brown to black pigment. It is an effective drier in paints, and apparently, in the days of wooden ships, was used as a preservative against attack by marine worms. It has also been mined, and calcined, for use in bleach and glass manufacture and is an important ore of manganese.

11.3 Locality: regional and national distributions

11.3.1 Barytes and Witherite

Barytes: This mineral is very widely distributed but has only been mined commercially in the Lake District, the edges of the North Pennine ore field, Derbyshire, Yorkshire, Southwest Shropshire and isolated mines in Devon and Somerset. Elsewhere in the UK it occurs in Wales, Scotland and Ireland.

Witherite: For many years, until closure in 1969, Settlingstones Mine in the North Pennines was the world's principal, and latterly only, producer of witherite. However, several other mines in the North Pennines and County Durham, including at least one coal mine, produced the substance. The only other records of English production are from Anglezarke in Lancashire, and from Shropshire, where Snailbeach Mine produced about 1000 tons and a few neighbouring mines produced a little.

Fluorspar: In Derbyshire, the mineral is generally confined to the eastern third of the limestone area from Castleton to Wirksworth. Some was found with tin in Devon and Cornwall. In the Mid- and North Pennines it occurs in the widespread mineral veins, with fluorspar being the dominant gangue in the centre of the field (and barytes around its fringe).

Calcite: As possibly the most common vein mineral, calcite is very widely distributed but does not seem to have been extracted everywhere it occurs. Derbyshire has produced the most and Shropshire produced a considerable quantity from about 10 mines; otherwise English production includes a little from Yorkshire and the Mendips (Several Welsh mines also produced a substantial quantity).

11.3.2 Pigments

Generally widespread (with the exception of graphite) and often worked in small quantities, or as a secondary (or lower) product. The Peak District seems to have been something of a centre with 'paint' mines in Manifold Valley and Dovedale area and paint mills at Milldale in Dovedale, Via Gellia and High Tor at least (Ford 2003, Paulson 1997).

Ochre: Widespread, though it may not have been worked specifically to any great extent outside Southwest England, Derbyshire and the Welsh borders. Incidental working at coal mines, and very small scale workings, will have been spread across most of the country.

Figure 11.5 A ropeway, one of two operating between 1918 and 1948 which served Malehurst Barytes Mill, Pontesbury Shropshire, one from Bog Mine and one from Huglith mine. © SCMC

Raddle: Haematite is widespread, though its working as a pigment is not; such workings are known in the Bristol/ Mendip area (Clarke et al. 2012), in Staffordshire, the Peak District and South Yorkshire around Hartington, Dovedale and Cauldon Low (Ford 2003).

Umber: This mineral has been extracted in the West Country at Ashburton in South Devon, Combe Martin and North Devon Mine, and Cumbria at China Clay Umber mine (Harestones). It is not as widespread as ochre.

Wad: This occurs in quite a number of places but is only known to have been worked extensively as a pigment in Derbyshire, where about 30 mines have produced it (Ford 2001b).

Graphite: Effectively, the only graphite mine (anywhere) was Seathwaite[6] Mine, Borrowdale, Cumbria (where it was called wad) (Lax and Maxwell 1998), though a little was claimed to have been found at Bannerdale Mine nearby. This latter being noted in various publications with one reference to the 'Bannerdale Pencil' (Wilson 1922).

An enterprise known as East Portlemouth Consols on the South Devon coast in 1859-61 was claimed to have been working plumbago but no production was recorded (Hamilton Jenkin 1974, 141).

Carbon Black is known commercially as Bideford Black and was produced from at least the 18th century by working carbonaceous, anthracitic clay seams in North Devon (Cleaver et al. 1994).

11.4 Geologies in brief

Barytes, calcite and fluorspar

In England these are generally vein minerals, frequently occurring with lead, zinc, copper, iron and other metals and in the case of witherite, coal (Collins 1972).

In the North Pennines, barytes and fluorspar both occur in lower Carboniferous sediments. In the South Pennines (Peak District), they occur in various measures of the limestone below shales, though this distribution is affected by volcanic beds (toadstones). Generally, fluorspar is found to east and barytes to west, though the division is not at all clearly defined and there is some overlap.

In Cumbria, barytes occurs in lower Palaeozoic rocks. In Shropshire, it occurs in Precambrian and Ordovician rocks, while in Devon and Somerset, it is found within Devonian and Carboniferous rocks.

Witherite

Witherite is much rarer than barytes; it occurs in lower Carboniferous strata in a few mines in the North Pennines as a vein mineral, like barytes in connection with lead etc, but also as a vein mineral in coal measures (Collins 1972, 27). The small Shropshire deposits were in Ordovician Mytton Flags.

Pigments

The iron based pigments, ochre, umber etc., are predominantly found as replacement deposits in association with Carboniferous limestone, although some Coal Measure ironstones have also been exploited for pigments. Carbon (mineral) black, as worked in the Bideford area of North Devon, is a stratified deposit found in association with anthracite seams in the lower part of the Carboniferous series. Graphite, on the other hand, is found as veins in fault fissures of volcanic origin in the (Ordovician) Borrowdale Volcanic Group (BGS, Cool Graphite, nd).

11.5 Historical research

The history and archaeology of gangue minerals have rarely been the focus of research or recording. This may be because the substances have been considered to be waste at some stage in their history; or because, generally, they were not mined for their metal content and did not have the 'alchemy' of smelting; or because they were a less important mineral that enabled a 'proper' mine to survive a few more years; or because they generally came late and don't have exciting stone engine houses, mystique or antiquity.

Worse, the remains of purely gangue mines are still seen as industrial dereliction not industrial heritage, and money is probably more forthcoming for site 'reclamation' (i.e. levelling of archaeological evidence) than conservation. To be realistic, some of those mines do not have much worthy of preservation though, it is very important that they are studied and recorded.

From the 1960s onwards, some surveys were carried out and the results contained in society libraries, e.g. Shropshire Caving and Mining Club (SCMC), or deposited in archives such as the L H Butcher collection at Weston Park Museum, Sheffield. Collections of photographs also exist, and both these sources should help inform future archaeological research.

Mining other than for fuel or metal ore is, with small scale exceptions (only flints and pigments), not an activity which developed significantly until the mid-19th century, and then quite spasmodically, with some mines producing a product which other mines in the same area treated as waste.

Barytes and Witherite

Some barytes was mined from the early 18th century. In 1729, the London Lead Company sent some to the capital from their mine at Nether Heath in Shropshire for unspecified purposes (Rhodes 1970). Josiah Wedgwood used substantial quantities in his Jasperware, which he perfected in the 1770s; this product also contained a small amount of witherite from Anglezarke mine. Despite this high profile use, relatively little research has been done, with the exceptions of mines at Anglezarke in Lancashire (Williamson 1963), the Teign Valley in Devon (Schmitz 1975) and Shropshire (Shaw 2007; 2009). A small amount was taken from a mine in Yorkshire in 1788 for an unspecified purpose.[7]

Fluorspar

Although the mining of fluorspar appears to go back further than that of barytes, available research into its history, like that of barytes, is patchy. The 18th century use is covered in PDMHS *Newsletter* (138, April 2011), and Blue John by Ford (2005a), with the subject covered more generally in Bramley (1991) and Dickinson (1965) amongst others.

Calcite

The mining of this mineral came on the scene even later than the above, and is even less researched (*but see* Ford 2002; Shaw 1995; 2002.

Pigments

With the exception of graphite, and with the possible exception of prehistoric sites (*see* Section 2), little research has been carried out on specifically pigment mines. Some work has been done on the Derbyshire (Paulson 1997) and South Gloucestershire (Williams 2010) paint and colour industry and on ochre in the Forest of Dean (Strassburger 2000); the industry in the Bristol/Mendip area is examined in some detail by Clarke et al. (2012). The paint industry at Brixham and Dartmouth in South Devon, based on local iron-based resources, was researched by Howard (2000) and such work provides significant detail on the extraction and subsequent processing of those resources.

Graphite, a high value product with limited scale mining, has been very well researched. Camden mentions it before 1610, and numerous writers (and cartographers) since have visited and noted the activity. Seathwaite mine in Borrowdale has been researched by field staff at the RCHME, who published an earthwork survey of surface remains and a documentary account (Lax & Maxwell 1998); an underground survey has been published by Wilkinson[8]. The Bannerdale site has also been researched (Adams 1995, Hewer 1984).

The production of carbon black in the Bideford, North Devon, area has been touched on in the history of anthracite mining (for example, Acworth 1992 and Edwards 2011, 35-57) but was the focus of research by Cleaver and others (1994) and a paper by Cubbon (2008). There is, however, a wealth of primary manuscript and printed material that might be used to support archaeological investigation

11.6 Technology

The methods used to work gangue minerals and pigments are those used for vein minerals. Deep mining, open-casting and, in a few cases, working deposits in natural caves occurred, usually for ochre or Blue John. Processing the various substances varied considerably, and is dealt with case by case below.

11.7 Field archaeology

11.7.1 Barytes and Witherite

Extractive sites

These minerals have generally been mined, some recovered from tips and a substantial quantity from opencast working notably in Cumbria. There are two types of site remains: firstly of lead and other metal mines, where the remains are not significantly related to barytes; secondly, mines developed for barytes. The latter are more or less all 20th century, with concrete, brick, steel or galvanised corrugated iron buildings/ruins/foundations and, if remaining, steel headframes and chimneys. Underground, many would have used tramways with haulage systems.

Processing

Minerals to be used for the chemical industry often left mine sites as a gravel. That for dense/filler uses required crushing and usually washing/bleaching, which has not infrequently been carried out at the mine site but equally often at centralised mills, the latter probably increasingly. Any remains will be similar to those above.

Movement of materials

Barytes mines have generally been in fairly remote locations and used tramways, road haulage and, in a significant number of places, aerial ropeways. Where tramways were used there are usually some remains of embankments, cuttings, abutments etc. Road haulage remains, whether by horse, steam, or internal combustion, are indistinguishable from the generality; in several cases, e.g. Cow Green, roads were specially constructed to serve mines (Fairburn 2005). Ropeways, especially in areas of low agricultural value, will have left foundations, as for example at Force Crag in Cumbria (Oswald et al. 2008) and Bog Mine in Shropshire, where the bases of the pylons survive (Fig 11.5).

Sources of power

Initially, purpose-built barytes mines used steam power, but, as the 20th century progressed, electric pumps and winders became the norm, often with the need for on-site generation either directly by coal, or using producer-gas plant. Remains of these electrical systems are scarce and fragmentary. Petrol and, later, diesel pumps and winches supplemented electricity. A similar pattern is seen at the mills.

Infrastructure

Generally developed either in long term mining areas or during periods of increasing personal mobility; communities have not developed specifically around barytes mines to a great extent, though there is at least one terrace in the North Pennines built for barytes miners and named after a Shropshire mine (Wrentnall Cottages at Langdon Beck to serve Cow Green Mine (Fairburn 2005)). In some places, 20th-century development will have continued as a result of barytes enabling a mine to stay in production for longer. These effects may be too subtle to quantify, though the following quote from the *Durham Regional Research Framework* suggesting research 'to develop a wider appreciation of life in lead mining settlements after the decline of the major lead companies' is significant (Petts & Gerrard 2006, 193).

11.7.2 Fluorspar

The above headings under barytes deliver very similar results for fluorspar. Probably the earliest mines dug primarily for fluorspar, other than Blue John, date from just into the 20th century, and fewer perhaps will have used steam power. Underground, many would have demanded tramways with haulage systems. A few, including Sallet Hole and Milldam, were on a scale to use road haulage. Processing is less likely to have taken place at the mine site. Modern processing methods are well described in Bramley (1991). The Blackdene processing plant was acquired and shipped to Morocco after closure; it may still remain and could possibly provide some information (B Moore *pers comm* - via mining-history email discussion group).

11.7.3 Calcite

Effectively, see the above entries for fluorspar and barytes.

11.7.4 Pigments

The small scale of this industry means it has left even less to study, Seathwaite Mine, Borrowdale being an honorable exception. Ochre has also been the subject of a field study in the Forest of Dean (Strassburger 2000).

Processing of iron-based pigments

Once mined, the processing of ochre and umber consisted primarily of grinding and drying. For that purpose mills were generally established close to the mines, sometimes referred to as 'paint or colour mills' (as with those at Matlock and Torbay). On some processing sites the heavy grinding wheels still survive - as at the Littleton Colour Mills and near the Red House mines at Winford, Somerset (Clarke et al. 2012, 32-57). The structure of a drying kiln, an essential part of the process, also survives at the Upper Littleton Mill (ibid, 37).

11.7.5 Graphite and Carbon Black

The RCHME carried out a measured survey of the site of Seathwaite on behalf of the National Trust in 1995 (Lax & Maxwell 1998). Adits, spoil heaps and an open pit survive and the remains of guard houses and other buildings. A washing floor was identified; washing constituting the only preparation required before the graphite could be used. Unusual survivals are three (of five original) boundary markers erected for John Banks (of Kingston Lacy, Dorset) in 1752. At Bannerdale, two small ruins survive and a ruined hut may be related to the graphite mining there.

Figure 11. 6 Rusting sheds and tram rails at the Bideford Black dressing sheds in 1970. © Michael Messenger

Originally, the material was moved by men or packhorses, though later a short tramway along an adit to the washing floor was constructed. During the mine's heyday, all the (legitimately obtained) material was shipped to London in casks, even that which was destined for the Keswick pencil works.

As with the iron-based pigments, ochre and umber, the processing of carbon black relied on drying and grinding, but by the 1930s Bideford Black Ltd had installed an oil flotation plant at their works to improve the separation of the carbon from unwanted waste. The plant, described by Morgans (1930), used wet grinding, flotation cells, and a thickener to concentrate the product before it was dried. The plant was evidently not entirely successful and the company reverted to basic grinding and drying (Edwards 2011, 54-57). Unfortunately, the plant was partly demolished and scrapped after abandonment in the 1970s, but the descriptions might inform any investigation of the surviving features (Fig 11.6). See Edwards (2011, 56) for a photograph of the processing plant in the 1930s.

11.8 Archaeological recording (by district)

11.8.1 Peak District (South Pennine orefield)

Barnatt and Penny (2004) have dealt with the survival of, and threats to, the Peak District's lead legacy. This publication acknowledges that gangue minerals, where exploited for their own economic value, have a history that often cannot be disentangled from that of lead. The report makes it clear that the suggestions made within

Figure 11.7 An abandoned crushing stone left after fluorspar operations at a Peak District mine. © Dave Williams

it have as much effect on gangue mineral archaeology as they do on lead, but that (chap 1.4) modern gangue mineral mining is seen realistically as having been one of the problems for the survival of mining archaeology in that area. Much of earlier interest has been destroyed, not least by reworking of the tips in attempts to exploit gangue minerals. The report also makes some very important points about the need to raise awareness and interest in these remains.

However, on hillocks in Derbyshire, some assessment has been carried out which relate to gangue (chap 4.23), while some fluorspar extraction sites are now of archaeological interest as well as acting as hosts to important plant communities (chap 3.19).

Also within the report, Appendix C contains 'detailed descriptions of the archaeological interest at all entries within the inventory of regionally important lead mining sites in the … ore field'.

11.8.2 Yorkshire

As in all other areas, most economically worked gangue was taken from tips or mines previously worked for lead, the exception being barytes from Raygill Mine near Skipton. A significant number of other mines produced barytes, fluorspar and calcite decreasingly into the 1990s. Remains, as elsewhere, are partial including many building foundations. 'At the former Dales Chemicals plant on Grassington Moor there are a few more significant remains of settlement dams and a circular de-sanding tank (M Gill *pers comm*). There are similar remains at the Clay Cross fluorspar plant at Dry Gill, Appletreewick. Both these plants were connected to the National Grid and could have remains of power lines or transformers (M Gill *pers com*).

11.8.3 Shropshire

Very little fluorspar has been won from this orefield. Claims that 900 tons of purple fluorspar were extracted between 1874 and 1879 were made by the mine's management in the official statistics (Burt 1990) at Snailbeach Mine; over a quarter of national production (Burt et al. 1990). However, at least one load did not fetch the price expected, and some (Dunham 1945, 107) have questioned if this load was purple calcite. If this was the case for one load then the rest might also have been calcite. If fluorspar was being worked here, the archaeology will have been destroyed by later mining.

Barytes and witherite were well represented in the county, with lead mines often turning later to this mineral. Also, there were several purely barytes mines including Huglith, which must have been one of, if not the, largest in the country between the wars. Archaeological studies have been carried out at Snailbeach and Tankerville Mines (*see* Section 7). Some limited surface recording has been done at Huglith (Heathcote 1980) and Cothercott (Shaw 2003), though much remains to be done (*see also* Shaw 2007; 2009).

A survey has been carried out on the remains of the two ropeways serving the barytes mines (Shaw et al. 2015).

Calcite became an important product at a number of the county's mines in the 20th century, notably at Snailbeach, where production re-working the 'white tip' was carried on as a one-man operation into the 1980s. All the archaeology was effaced with the re-grading of the tip in the 1990s.

11.8.4 Southwest England and Gloucestershire

There are no known fluorspar remains and little is known at barytes mines. Mines were standard 20th century vein mineral mines, generally the site was cleared as mine closed (Cranstone 1993b, 18). At Bridford Barytes Mine in Devon, abandoned in 1958 (Richardson 1992, 83), waste heaps and water-filled settling ponds are all that remain following demolition (Clark 1995, 15-17), although detailed field investigation would undoubtedly reveal more.

Some calcite was formed in veins, but, apart from some mining in the Mendips, it does not seem to have been exploited. Ochre production has left remains in the Forest of Dean, South Gloucestershire, and around Bristol and Mendip in Somerset. The field evidence for the latter area, including underground features and the processing plants, was examined in detail by Clarke and others (2012). Their work provides an excellent basis for further research.

Figure 11.8 The head-frame at No2 shaft, Grove Rake - still a significant feature in the historic mining landscape in the Rookhope valley, north of Weardale. The head-frame at the adjoining No 1 shaft was stolen for scrap a few years ago.© Peter Claughton

In Devon, the processing of umber at Combe Martin has been touched on by Claughton (2004, 29) and the ochre working associated with the Torbay Paint Company was covered by Howard (2000) but there has been little, if any, supporting archaeological investigation. The Bideford Black processing mill at East the Water was investigated by Messenger in the 1970s prior to its demolition primarily in relation to its tramway system but remains unpublished (Michael Messenger *pers comm*). Archaeological investigation of the culm mines at East the Water, Bideford, in advance of road building, would have intersected some paint seam workings but they are not highlighted (*see* Edwards 2011, 43-44).

11.8.5 North Pennines and Cumbria

Within this orefield, there are some survivals associated with gangues and pigments. Petts and Gerrard noted headgear at Grove Rake, and evidence at Middlehope Old Mine. They also stated that such are not often listed or scheduled (Petts & Gerrard 2006, 113). English Heritage has undertaken investigations at Force Crag zinc and barytes mine site, the results of which are to be found in two research reports (Oswald et al. 1999; 2008). This is a Scheduled Monument and is on the 'at risk' list. An archaeological survey was carried out by the RCHME at Seathwaite Mine for the National Trust (Lax 1998). At Bannerdale levels remain open, one being called the Graphite Level, there are also surface remains (Adams 1995).

The above assessment has not attempted to note coal mines where ochre production has occurred, presumably little, if any direct remains exist.

11.9 Crosscutting themes

Given the nature and date of mining of what had sometimes been considered gangue materials, many of the possible themes are crosscutting, both with earlier mining and communities, but also with the reuse of sites; a few as industrial estates, transport yards or single factories and many as official or unofficial tips and/or scrap yards. Aspects of life in a mining community after the cessation of lead mining, have been collected by Francis (2000), and in a series of recordings made and held by Shropshire Mines Trust[9], including recollections of many former barytes miners; similar important interpretive material will exist in other areas. The uses of calcite, some fluorspar and the pigments, being principally decorative, could

provide important context for archaeologies of human expression through material culture, particularly in the 19th and 20th centuries but also in much earlier times. Pigments have at once multifarious and nebulous other connotations, ranging from the earliest cave paintings, through cosmetics, medicine and building decoration to canvas preservation for Brixham's fishing fleet (Red Sails in the Sunset).[10] There is no specific infrastructure related to the industry, though its security concerns were notable, with the guardhouses at Seathwaite to stop miners leaving with graphite, an armed raid and an Act of Parliament to make it a felony to steal the substance. The likes of Black Sall and the Dandy Wad Stealer are still remembered and in the former case 'celebrated' as 'Hare and Hounds' on the fell each Whit since 1898.[11]

11.10 Late 19th and 20th century ore preparation techniques, including flotation

11.10.1 Introduction

In the late 19th century, a combination of falling metal prices and increased demand for minerals that had previously been discarded, meant that many British mines were erecting large complex gravity separation plants to process their ores. Mines whose output had been focussed on just the one metal were becoming poly-metallic ore producers, but real advances in the separation of those ores did not come until the 20th century and the full development of froth flotation.

By the 18th century, non-ferrous metal ore preparation (ore dressing) had already become quite complex, although some mines and mining fields in England were slow to take up new techniques (*see* Barnatt 2011, 148-49, and an account of ore dressing technique in Derbyshire). There was increased mechanisation in crushing and separating metalliferous minerals from the gangue minerals and waste rock, but preparation still relied on gravity separation in water using tried and tested methods such as buddles and jigs, frequently referred to as 'washing' (*see* Burt 1982). At that period, however, most ore deposits worked in England were dominated by a single metal sulphide, in the case of lead and copper, or the oxide in the case of tin, with little requirement to separate out other metalliferous minerals. In the mid to late 19th century ore preparation began to change as the value of minor mineral content in some deposits began to increase. For example, the separation and preparation of zinc concentrates often supported continued mining of lead.

Ore preparation became increasingly difficult as mines sought to separate out minor minerals when prices increased and a greater number of poly-metallic deposits were exploited: deposits, which in earlier periods might have been ignored as being too difficult or costly to process. As a consequence, gravity separation plants became increasingly sophisticated in attempts to separate minerals of very similar specific gravity. The plant installed in mid-Wales at Cwmystwyth in 1900, illustrated in detail by Henry Davies (1902, 455-59) and described as being the most advanced of its type, was typical of such developments. They were, however, incapable of dealing with the most complex poly-metallic deposits.

The real breakthrough in ore preparation came in the 1890s with the development of bulk oil flotation. This development, by Francis and Alexander Elmore, built on earlier work showing that some minerals had a tendency to attach to certain oils. This work had begun in the 1860s and had already led to the development of new techniques such as the Wilfley table. Experimenting with flotation, where oils were used to bring selected minerals to the surface of a mixture of finely crushed ore, water and oil, continued at the Glasdir Mine, in Merionethshire (Wales), into the early 20th century with the introduction of air bubbles to the mixture and the application of a vacuum to the process. A commercial flotation plant was built in Australia at Broken Hill, New South Wales, in 1905 and others were erected in South Africa, in Canada, and in England and Wales (*see* Jenkins 2001, 74-98, for details of the early use of the process). The use of oil in these early plants was excessive and they all eventually failed, but it was further experimentation at Broken Hill which led to the successful development of froth flotation with the introduction of gas bubbles and reduced oil usage. That work, along with the parallel development of skin flotation, where sulphide minerals were found to adhere to the surface of a water and oil mix, led to successful commercial flotation plants which continue to be used today (Bunyack 1998, 23-33; *see also*, Short 1997 and Shelley 1998). In association with the development of flotation came the development of new crushing techniques capable of reducing the ores to the fine consistency required for flotation, rod and ball mills, and refinement of mechanical classifiers and shaking tables such as the Wilfley to assist in the separation phases of the process. It is a combination of those techniques, not just the flotation process itself, which make up the modern ore preparation (in modern terms, beneficiation) mill.

11.10.2 Archaeology

Very little investigation of these specialist ore preparation sites has been carried out in England. Not since the

1980s and the work of Palmer and Neaverson (1989) and Cranstone (1989) has there been a concerted effort to record and interpret the physical evidence for gravity separation of non-ferrous metal ores in England from the mid- to late-19th century. Some sites dating from before the advent of mechanisation have been investigated, for example Willies (1998) investigated the lead dressing floors at Winster Pitts and the investigation of the High Rake Mine, also in Derbyshire, revealed a relatively un-mechanised dressing floor from the mid-19th century (Barnatt 2011, 64-73), and others are cited in the resource assessments for lead, tin and copper. In 2002 an 'excavation', without archaeological supervision was carried out on a section of the upper dressing floor at the Deep Ecton Mine in Staffordshire, revealing elements of a round buddle and launder. The level of recording at the time is unclear but the excavation was made safe and back-filled by members of the Peak District Mines Historical Society and some details, including a plan of the site, have subsequently appeared in John Barrnatt's book on the archaeology of the Ecton mines (2013, 34-36).

There has, however, in recent years been significant work carried out in Wales. Mechanised dressing floors on a number of sites in Mid-Wales, at Bronfloyd and Cwmbyr, have been excavated by the Welsh Mines Preservation Trust, building on work carried earlier at Craig-goch. The work has been published in outline in the Trust's newsletters (WMPT 2011, 10-31)[12] and measured drawings are being archived. Excavation and interpretation are on-going and comparisons with ore dressing practice in County Wicklow (Ireland) are planned for the future, initiated as part of the European Union InterReg 4A funded Metal Links project. Recent work at Frongoch has also revealed considerable detail on the modification of dressing floors over time (Murphy 2015).

We also have to look to Wales for evidence of the early flotation process, with Elmore's prototype plant at Glasdir in Merionethshire, replaced in 1907 by a commercial scale Elmore plant, using the vacuum process (Jenkins 2001, 87). Unfortunately, once abandoned, most plants were scrapped and the physical evidence is largely confined to the concrete loadings for the various components of the plant. See Short (1997, 93) for a list of sites with surviving evidence, most of which are in Wales. Only a few plants survive intact or, at least, partially intact on metal mining sites in England. There is the relatively modern plant with some associated features at the Geevor Museum in Cornwall. At Force Crag, near Keswick in Cumbria, where an Elmore designed plant was erected in 1914, there are the remains of a later flotation plant installed in1939-40, later modified and used up until the 1980s. The mine and the surviving plant are in the custody of the National Trust and have been recorded in detail by English Heritage (English Heritage Archives AF1300081).[13] Other flotation plants survive, and have been recorded, outside Britain - notably the Shenandoah-Dives plant at Silverton, in Colorado (Bunyack 1998). Flotation was, however, used extensively in the separation of gangue minerals, fluorspar and barytes in particular, and plant used for that purpose survives on sites such as the Cavendish mill in Derbyshire, still in use but as yet, unrecorded.

Notes and Internet sources

1. Petts, D and Gerrard, C, 2006 Shared Visions, Durham County Council http://content.durham.gov.uk/pdfrepository/nerffbook2.pdf
2. http://en.wikipedia.org/wiki/fluorite
3. http://www.britishfluorspar.com/eng/about-us/location/ [accessed 3 December 2015]
4. www.ukminingventures.com/weardalemines.htm
5. www.conistonlocal.co.uk/striking-black-gold-in-the-lakeland-fell-tops-1.692082?referrerpath=home
6. It seems to be called Borrowdale Mine more frequently than Seathwaite.
7. Chatsworth MSS: 12/02/1788 Letter from G Bradley to B Hotham, via M Gill
8. www.aditnow.co.uk/documents/borrowdalegraphite-mine/graphite-at-seathwaite-June-2012.pdf
9. http://shropshiremines.org.uk/index.htm CD recordings of miners' (inter alia) memories, held by SMT recorded 1998 - 2000
10. http://en.wikipedia.org/wiki/brixham
11. http://upnoutside.wordpress.com/tag/seathwaite
12. Welsh Mines Preservation Trust (WMPT) 2011 Newsletter [PDF document] www.scribd.com/doc/65374202/welsh-mines-preservation-trust-newsletter-summer-2011 [accessed 25 April 2012]
13. English Heritage Archives, AF1300081 Force Crag, Cumbria, catalogue reference [Web document] www.englishheritagearchives.org.uk/singleresult/default.aspx?id=1297488&t=quick&l=exact&cr=AF1300081&io=False URL [accessed 25 April 2012]

12 Minor Metals and Minerals

Peter Claughton

12.1 Alum and copperas

12.1.1 Introduction

Alum and copperas were important to the developing textile industry in the post-medieval period as mordants, used in fixing the dyes used on woollen cloth, and both chemicals had roles in the production of leather. Copperas was an ingredient of ink and many claims for its effectiveness in a variety of medicines were made, while alum also served as a water purifier and as means of enhancing the quality of paper. Prior to the 16th century both were imported into England from producers in the eastern Mediterranean and, later, from Papal territory in Italy where the Pope maintained a monopoly on production and trade. In the second half of the 16th century, copperas, and from the early 17th century, alum, were successfully produced in England, although it was over a century before imports of the latter were totally replaced by home production.

Alum (a double-salt of aluminium sulphate plus an alkali, either potash or ammonia) was initially produced on the Isle of Wight and in Dorset (but see below), utilising pyritic shale of Eocene age. The focus of production then moved to Yorkshire in the early 17th century where, after a faltering start, the process was mastered and production increased. Other peripheral centres of production existed in England, notably at Pleasington, in Lancashire. Initially, until 1679, the trade was protected by either a Royal monopoly or patent rights but production was sustained through to the late-19th century. Competitive pressures started in the late 18th century with the development of production processes at other centres; at Hurlet in Scotland, for example an improved burning technique increased the yield and speed of production (Skillen 1989, 54). Elsewhere the use of cheap, high volume resources, such as colliery waste, was developed on an industrial scale at Pendleton in Lancashire and, later, at Goole in Yorkshire from the 1840s onwards (Marshall 1995, 41). Added to which, changes in the textile mix and the use of artificial dyes, all side-lined the Yorkshire industry to the point of gradual closure around 1870.

Copperas, hydrated ferrous sulphate ($FeSO^4$-$7H^2O$), also known as green vitriol, was produced from the iron pyrite nodules found in the London Clay across a wide area of Southeast England and around the Thames estuary. It also occurred in certain seams in the coalfields, and from pyritic shale on the Dorset coast and the Isle of Wight. As a mordant, it was not as effective, nor as valuable, as alum but it had other uses in tanning processes, as a black dye, in the production of writing ink and, until the mid-18th century, as a source of sulphuric acid. It was first produced in England, in Kent, in the 1560s (Allen et al. 2001, 97) and production continued there until the late 19th century. It was also produced in Dorset and on the Isle of Wight, and much of what is recorded as 'alum' production from those areas in the late-16th century may have been in reality, given the poor understanding of the techniques at the time, copperas (Jecock 2009, 56).

12.1.2 Geology

For alum production the requirement was for rock having high levels of the aluminium sulphate needed as feedstock, along with a high carbon content, which assisted in the calcining process (the alkali was added later during manufacture). With copperas it was the pyrite (iron disulphide), disseminated in the shale or present as nodules, as found in the London Clays and in the pyrite rich seams within the coal deposits of Carboniferous (Namurian and Westphalian) age, which provided the feedstock. Both alum and copperas production utilised rocks of Jurassic (Eocene) age found extensively across southern England and the Midlands up to Northeast Yorkshire, but concentrated on coastal exposures where the strata, pyrite-bearing clays or pyritic shale, were easily accessible. In Lancashire, at Pleasington, the shale worked in the alum quarries was of Namurian age in the Millstone Grit formation (Price et al. 1963, 98).

12.1.3 Historical context

The demand for mordants by the expanding post-medieval textile industry, encouraged experimentation in processes utilising English mineral resources. The earliest patent for such a process, granted to William Kendall of Launceston in 1562 to search for and produce alum in the southern counties of England, failed, but others were encouraged to continue the search. Large sums of money were expended on attempts to work the shale deposits along the Dorset coast with very limited success, though the industry is immortalised in Bournemouth by the topographical feature known as Alum Chine. Some alum was allegedly produced during this episode but the majority of the output was copperas (Bettey 1982). Assisted by imported expertise from continental Europe, copperas production expanded in the last quarter of the 16th century, with North Kent and the shores around the Thames estuary at the forefront. Iron pyrites nodules, eroded from the London Clay, were collected along the shoreline and taken for processing at copperas works such as that at Whitstable, which continued to operate through to the early part of the 19th century (Allen et al. 2001). At Queenborough, on the Isle of Sheppey, copperas was processed until 1882 (*ibid*, 96). As the knowledge necessary for copperas production disseminated, works were set up on the coalfields, as at Almondbury, near Huddersfield, supplied directly from a nearby colliery (Brook (nd) citing *Leeds Mercury* 8 Feb 1806), or that at Shevington, near Wigan (Blakeman 2007, 11). In Shropshire, Brown (2004) has noted that pyrites production from the coalfield continued beyond the end of the 19th century, with one mine in particular, the Rock Mine, supplying the Wrekin Chemical Works (Fig 12.1) into the 1920s.

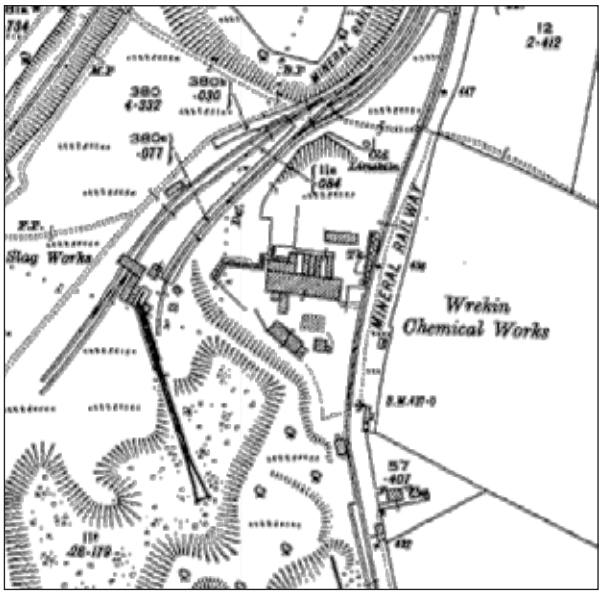

Figure 12.1 Wrekin Chemical Works in the 1920s, in the area now known as Town Park, south of Telford town centre (OS 1:2500 mapping, 1927).

Continental European specialists may have had an impact in the development of techniques for alum production, but the establishment of the industry on the coast of Northeast Yorkshire appears to have been driven by local interests, although the exact sequence of events is unclear. The first alum works are likely to have been those established at Slape Wath on the Skelton estate in about 1604, followed by four others at Sandsend, Mulgrave, Belman Bank and Newgate Bank within five years. Further expansion was restricted by patent monopoly, in place until 1679. Thereafter, upwards of 26 alum shale quarries with their associated processing sites, calciners and alum houses, were worked along the coast and inland as far as Thimbleby, Carlton Banks, Kirkby and Great Ayton. All were exploiting the pyritic Alum Shale as feedstock for the production of the aluminium sulphate, which was the key component used in alum production. The last works, Boulby, did not close until 1871 (Marshall 1995, 40-41; Jecock 2009, 55-58).

While Northeast Yorkshire was the major producer of alum prior to the mid-19th century, there was some production from an isolated site in Lancashire. There, shales below the Alum Crag Grit, about one mile north of Pleasington, were worked intermittently between 1609 and the late 18th century. Production costs were probably higher than those in Yorkshire but the proximity of a market in the local leather and textile industries ensured continued demand through the 17th century at least (HE Pastscape, Pleasington).

The alum industry, based on the extraction of pyritic shale, was overtaken in the 19th century by large-scale production of sulphuric acid, which allowed bulk, low-grade sources of aluminium sulphate, including colliery waste, to be treated economically (Marshall 1995, 41). It was probably in connection with this, the Spence process, that Alum Shale was being worked at the Wallsend Main Colliery, near Barnsley in the period 1895 to 1906 (List of Mines). Even the high grade aluminium sulphate-rich shale worked at Hurlet in Scotland, ceased to be worked by the late 19th century (Skillen 1989). For copperas, new technologies in the second part of the 19th century marked the demise of the industry. These included the introduction of synthetic dyes and large scale processes, such as the 'contact process', introduced in the 1870s for producing sulphuric acid. Small scale operations based on the processing of pyrites from the London Clay, or the coalfield deposits, were no longer viable in the face of developments in the rapidly expanding chemical industry.

The history of alum, its uses and production from

ancient origins to modern times, was covered in a seminal work of 1948 by Charles Singer.[1] The historical evidence for alum production in England has been addressed by a number of authors, usually working on a more local scale. For example Bettey's work in Dorset (1982 and 2001), and studies based around Northeast Yorkshire by Pybus & Rushton (1991), Marshall (1995) and Jecock (2009); the latter two as background to archaeological investigation. Allen et al. (2001) have provided an account for copperas in Southeast England. In contrast, the production of copperas on the coalfields has largely been ignored, while the value of iron pyrites as a co-product with coal, and the associated copperas works, are generally not considered by historians of that industry. Hatcher (1993, 445-46) sees the copperas industry in Southeast England as a significant consumer of coal but neither he nor the authors of succeeding volumes of The History of the British Coal Industry make reference to the mining of iron pyrites alongside coal and its subsequent processing as copperas. There are, however, occasional reference to pyrites and copperas production in the histories of particular collieries (e.g. Dickinson & Holding 1965).

12.1.4 Infrastructure

Both alum and copperas production consumed large amounts of coal and were ideally located close to suitable supplies, either shipped in by sea, or direct from the collieries. Purpose-built harbours and quays, or staithes, close to the alum houses were a feature of the industry on the coast of Northeast Yorkshire, often constructed at the base of the cliffs, with rut-ways on the foreshore allowing carts access to the ships at all states of the tide (Jecock 2009, 69-70). At Boulby, a vertical haulage shaft was sunk in the late 17th century to connect the foreshore to an alum house located on the cliff top, and by the 19th century at least one inclined tramway was in use at the Ravenscar Alum Works (Marshall 1995, 55-57). The copperas works on the Thames estuary were located adjoining the foreshore, close to the source of the pyrites nodules and where beached colliers could unload their cargo (Allen et al. 2001). In the coalfields, tramways were the preferred means of transport, with networks linking the collieries to the copperas works (*e.g.* Blakeman 2007, 11, map).

Water supplies were also essential to both industries and, for the cliff top alum quarries and calcining places, elaborate leat systems were in place to ensure a continuous supply (Jecock 2009, 64-65 & Fig 11).

12.1.5 Technology

There were no special techniques employed in the extraction of alum shale or the collection of the pyrite nodules used in copperas production, but the processing methods used were unique to the industries and invariably carried out close to the point of extraction.

Figure 12.2 General view north across the alum-house shelf at Kettleness. Keith Buck, © Historic England

The alum quarries were constrained by their locations, working particular horizons in the shale with elevated aluminium sulphate content, and tending to migrate laterally along the outcrop of the strata rather than following it in depth below increased amounts of overburden. The quarry faces were worked by hand in steps, allowing the shale to fall or be barrowed to the base of the quarry where the calcining places were located, intimately linking extraction to the first stage in the processing. Calcining was carried out in clamps up to 30m in height and 61m in diameter, initiated using furze as the fuel and sustained by the organic material within the shale. Clamps could burn for many months before they had exhausted their carbon content; it might be 18 months before they had cooled sufficiently to allow water to be added, as the reaction which enriched the aluminium sulphate content needed to be at low temperature. The resulting material was then steeped in large tanks of water and the resulting liquor channelled to the alum house.

Whereas the quarries and calcining places were located at the outcrop of suitable shale, very often at the cliff tops, the alum houses were generally built close to the foreshore and so positioned to reduce the cost of transporting the large amounts of coal required for the evaporation pans. The aluminium sulphate liquor could be fed by gravity into large tanks at the alum house, where a suitable alkali, either human urine

or kelp, was added to create a double sulphate with reduced solubility in water. After evaporation to achieve a set specific gravity, the liquor was allowed to cool at which point the alum crystals could be recovered and cleared to remove impurities before being allowed to solidify, a process known as 'roaching'. The full series of processes, from calcining to the finished product, are described in detail by Marshall (1995, 41-54) and Jecock (2009, 58-69), with the former providing greater detail on the operation of the alum house.

For the production of copperas, the pyrites nodules (often referred to as 'copperas stones') were broken up, placed in long heaps 1m – 3m high and exposed to the action of the rain over a long period, in some cases between four and six years, with the resulting liquor being channelled into tanks. This was then fed to evaporation pans where scrap iron was added and the liquor boiled to effect its concentration. On cooling, the copperas would crystallise out on to ropes, wooden rods or twigs inserted for that purpose. Allen et al. (2001, 98-100) provide a description of the process used at Whitstable and variations of that were probably practised at other sites. The liquor could also be used as the raw material for sulphuric acid production, prior to the development of the large scale industrial processes in the 19th century.

12.1.6 Archaeological recording

Certain aspects of the archaeology of both the alum and copperas industries have been investigated in some detail, but others have received relatively little attention and are poorly represented in the archaeological record. The alum industry in Northeast Yorkshire has been the subject of significant archaeological investigation led, initially, by members of the Cleveland Industrial Archaeology Society, who have excavated at least one site (Chapman 1975). In the 1990s, after the National Trust had acquired large sections of the Yorkshire coast, including many alum production sites, the Trust implemented a programme of recording and interpreting the evidence. Two sites, Ravenscar and Saltwick, were surveyed in detail (Marshall 1995) and an assessment was carried out at Loftus (Marshall 1993).

Figure 12.3 Displaced gutter stones at Kettleness alum works near Scarborough, North Yorkshire. © Historic England

In the late 1990s, surviving elements of the alum industry were identified as being located in areas subject to significant coastal erosion (Chitty 1996). Of the four sites considered to be at greatest risk, Ravenscar and Saltwick had already been surveyed, so attention focussed on Kettleness and Loftus, which were investigated by English Heritage (Jecock et al. 2003; Hunt et al. 2004). At the same time, *c* 2002 to 2004, opportunity was taken to survey the Stow Brow quarries (Oswald et al. 2005) and an associated alum house (Jecock *in prep*), and to assist in the survey of the Ayton Bank works (Pearson & Hunt, 2004). Carlton Bank, a site which is away from the coast, was surveyed by Oxford Archaeology in 1997 and published in *Steeped in History* (Miller 2002).

Although the survey work on the coastal alum works has been extensive, and many of the surviving visible features have been recorded, relatively little excavation has been carried out. However, some excavation has been completed at Boulby (Chapman 1975), followed by further detailed investigation in 1992 by the Cleveland Archaeology Section (Ponsford 1993, 280-81), the alum house at the Saltwick works was excavated in the early 1990s and some clearance work was evidently carried on the Peak alum house to reveal hidden features (Marshall 1994). Lee (2006, 77-80) provides an outline of what has been carried out within the North York Moor National Park but, as Jecock (2009, 68) points out, more work is required to determine how representative those houses are of the wider industry. Further investigation, including clearance work and excavation, is perhaps essential if some features are to be recorded in full before they are lost to coastal erosion (*ibid*, Fig 14).

Outside Yorkshire, the quarries and associated features of the early 17th to late 18th century Pleasington alum works (near Blackburn, Lancashire) were assessed for the English Heritage Monument Protection Programme. Although now designated as a scheduled monument, there has been no detailed

archaeological investigation (EH Pastscape, Pleasington). On the Dorset coast, alum and copperas mines, along with intertidal works dating from the late 16th and 17th centuries, have been identified on Brownsea Island and at Kimmeridge (Wessex Archaeology 2004, 22, citing Papworth 1992). The Dorset Alum and Copperas Industries Project has subsequently investigated a number of potential extraction and processing sites with excavation being carried out on three sites, at Brownsea (Tatler et al. 2009), Studland (Trevarthen et al. 2009) and Kimmeridge (Trevarthen et al. 2010), all of which were associated with alum or copperas processing. Detailed investigation of extraction sites has yet to be carried out.

The evidence for copperas production at Whitstable in Kent has been investigated in some detail, including the excavation of surviving features on what is now the foreshore in 1998 (Allen et al. 2001). It is, however, only one of a large number of sites for processing copperas known around the Thames estuary. Copperas works, and their associated extraction sites in the coalfields, have been referred to occasionally in historical studies, with at least 22 having been identified within the coalfields via historic map sources (Mike Gill *pers comm*). However, details are notably absent from the archaeological record, with very little investigation so far carried out at any level. A copperas works was identified at Ringinglow near Sheffield in the course of a desk based study (Badcock 2000, 10-11) but, although a number of surviving features were noted, no further investigation was carried out as they lay outside the study area.

Notes

Singer (1948) considered alum to be the earliest chemical industry in England but as Allen and others (2001) point out, it was preceded by the copperas industry.

12.2 Antimony

12.2.1 Introduction

In metallurgy, antimony was used in alloys for printer's type, in the preparation of anti-friction metals and for hardening lead. It was also used as an alloy, at from 5 to 10 per cent, with tin in the production of Britannia metal. Antimony compounds were also used as de-oxidisers and colourants in glass, pottery, pigments and dyes. From an early period, antimony compounds were also used in cosmetics and for medicinal purposes, and, as such, can turn up in the archaeological record (Watson 2013, 21). A small number of mines in the 19th century and earlier, primarily in Cornwall, produced antimony concentrates as a co-product, and a few were promoted with antimony as their principal product.

12.2.2 Geology

The principal ore of antimony is the sulphide stibnite (Sb_2S_3), although the antimony-lead sulphosalt ($PB_4FeSb_6S_{14}$) has been worked in some mines.

The antimony at the Louisa Mine, in Dumfries and Galloway, is associated with stratiform arsenopyrite-pyrite mineralisation in a Silurian greywacke sequence with similarities to that in the Clontibret area, County Monaghan (Gallagher et al. 1983, 24). The latter is associated with gold, and antimony has been associated with gold mineralisation in the vicinity of Port Isaac, Cornwall. Work by Clayton and others (1990) links the antimony in that part of Cornwall to stratiform pre-granite mineralisation, and whilst there has been little or no investigation of antimony mineralisation in Southeast Cornwall, it is probably of a similar origin (*see* Scrivener & Shepherd 1998 on stratiform mineralisation in general in Cornwall). To the north-east of Bassenthwaite, in Cumbria, work by Fortey and others (1984) again links the antimony to stratiform mineralisation similar to that in Dumfries and Galloway.

12.2.3 Historical context

Very few mines in Britain produced antimony ores in significant quantities, and these appear to have been confined to Cornwall, Cumbria and parts of Scotland. Antimony minerals are reported elsewhere but with no known record of production. In Cornwall, at Wheal Leigh near Pillaton to the north-west of Saltash, antimony is said to have been worked from the late 16th century (Beer 1988, xxi). A mine, or mines, in the Pillaton area reportedly produced 25 tons of ore in the 1770s and over 130 tons of ore in the 1820s. Around Port Isaac in North Cornwall, and particularly in the parish of Endellion, antimony was being worked by the mid-18th century, with production levels of around 95 tons from Wheal Boys in the 1770s (De La Beche 1839, 615-16). Lysons (1814, 194-216, citing Pryce, *Mineralogia Cornubiesis*) noted that a works for producing *regulus* of antimony was set up by a Mr Reed at Feock, close to Falmouth, and De La Beche (1839, 616) gives a date of 1778 for the works. A small number of mines in both these areas of Cornwall continued to produce small amounts of antimony ore in the second half of the 19th century (Burt et al. 1987, xxxii). Small amounts of ore were also produced from mines in Cumbria, to the north-east of Bassenthwaite on the western edge of the Caldbeck Fells. These were worked prior to 1816 (Lysons 1816, cxi), and again in the 1840s, but

information on the extent of those workings is limited.

The best study of antimony mining and the processing of the ores in Britain comes from the southwest of Scotland and the working of the Louisa Mine at Glendining, in Dumfries and Galloway, and the work there can inform that which should be carried out in England. The history of the Louisa Mine, the antimony at which was first worked in 1793, was researched by McCracken (1965) at about the same period that it was examined by Charles Daniel in connection with other work in the area (Tylecote 1983, 43 n. 1). Slag from the smelting process on site was analysed by Tylecote (1983), and the site was subsequently surveyed and included in the RCAHMS publication on the historic landscape of eastern Dumfrieshire (RCAHMS 1997, 276-77).

12.2.4 Technology

The mining and ore preparation methods employed in working antimony ores were little different to those used in the other hard rock, non-ferrous, metal mining sectors. Stibnite, the antimony sulphide, has a specific gravity well below that of galena, the lead sulphide with which it was commonly found in mixed ore deposits, and could therefore be easily separated by conventional dressing methods. Jamesonite, the antimony-lead sulphosalt, was a different matter with the lead and antimony in chemical combination, from which the antimony would be separated after smelting. Smelting of antimony ores to a metallic regulus was a specialist liquation process, carried out on site at Glendining in the 1790s and described in detail in the contemporary Statistical Account of Scotland (Sinclair 1791-99, II, 525-27). Evidently, the process was also carried out on at least one mine in Cornwall, Pengenna, near Port Isaac, where 'old smelting works remain at Watergate, near the adit mouth, where much slag, rich in antimony, still lies' (Dewey 1920, 50). Processing was also carried out at Feock in Cornwall, albeit away from the mining sites (Lysons 1814, 194-216), but little detail is available and the site of the process has not been investigated.

Given that the presence of antimony could be a significant contaminant in lead, hardening it to the extent that it was brittle and no longer malleable; many producers were at pains to remove it. Softening hearths where antimony and other contaminants would be removed might be found at a number of lead smelters and Gill (2001, 95-96) describes such a hearth at Old Gang, Swaledale, confusingly known as the 'Silver House' although, as the process involved skimming contaminants from the surface of lead maintained in a molten state, it may have been confused with the Pattinson process for silver enrichment. There is, however, no evidence that the antimony was recovered as a marketable product.

12.2.5 Infrastructure

There is no evidence of any elements within the infrastructure of mining in England which specifically supported the production of antimony. In Scotland, however, the settlement of Jamestown, in the parish of Westerkirk, Dumfries and Galloway, was built by the company operating the Louisa Mine in the 1790s, along with an access road and bridges. In Jamestown, the company also instituted a miners' library which survives (McCracken 1965, 143-44 and Appendix).

12.2.6 Archaeological recording

There has, as yet, been no archaeological investigation of antimony mines, or the preparation and smelting of antimony ores in England. The limited amount of investigation done at Glendining, in Scotland (RCAHMS 1997, 276-77), including analysis of the slag from the smelter carried out by Tylecote (1983), with the benefit of a contemporary account of operations in the 1790s (Sinclair 1791-99, II, 525-27), could provide information relevant to the investigation of sites in England.

12.3 Arsenic

Arsenic was one of a number of contaminants affecting copper and tin production in Cornwall and Devon. In the case of tin, where alluvial tin deposits were worked the arsenic had already been eliminated through weathering and leaching as part of the process of natural erosion, and was not usually a problem. However, *in situ* tin lodes, were often contaminated with arsenic and, as production from this source increased from about the 15th century, the arsenic, along with other contaminants (including iron pyrites, FeS^2 and zinc sulphide, ZnS), had to be removed by calcining the ore prior to smelting. A similar problem was attached to the exploitation of sulphide copper ores from the 18th century onwards, as mining progressed below the weathered secondary ores close to surface, and it became necessary to roast the ores to remove these contaminants by burning them off as gases. Burning houses or reverberatory calciners used for this purpose were recorded by the anonymous writer of 1671; although no structures remain from this period, later examples from the 19th century survive at some mines in both Devon and Cornwall. Prior to the early 19th century this process was carried out without any attempt to recover the arsenic, which was lost to the atmosphere. Mine owners in Cornwall and West Devon were slow to recognise the economic potential in recovering arsenic in the form of the arsenious oxide

(As_2O_3) but, once accepted, most large mines engaged in the practice, and by the 1870s some mines were realising a significant income from arsenic sales.

By the mid-19th century, the uses for arsenic compounds were manifold. It was added to molten lead in the manufacture of shot to produce a spherical shape and arsenical oxides were used in certain chemical processes as well as being used in the preparation of pigments for paint and wallpaper. It is a powerful poison and was employed in the preparation of sheep dip and other insecticides, such as crop dusts and sprays. The most important application for the latter in the late 19th to early 20th century was the control of Colorado beetle in North American potato crops, but the most well-known use, the control of boll weevil infestation in cotton plants in the 1920s, came too late to draw on English arsenic production (Burt 1988, 15-18).

Levels of arsenic contamination in copper ores from other mines in England were, perhaps, not as great as those in Devon and Cornwall but it was, never the less, still a problem, which had to be eliminated. At Alderley Edge this was achieved as part of the acid leaching process and the arsenic was removed as waste along with the sand (Carlon & Dibben 2012, 74). Arsenic does not appear to have been recovered at these, or any other, copper mine in England outside Devon and Cornwall. A small quantity was recovered from tungsten-bearing ores at the Carrock Fell Mine, in what is now Cumbria, and it was worked as the primary produce in Scotland at the Talnotry Mine near Newton Stewart, in Dumfries and Galloway (Pickin 2013).

12.3.1 Geology

In England, the presence of significant amounts of arsenic in copper and tin is associated with mineralisation linked to the Cornubian granite emplacement in Devon and Cornwall. Although arsenic is present in some ores in Cheshire (Alderley Edge), and the Northwest, in what is now known as Cumbria, it might have been regarded as a contaminant. But it was not present in sufficient quantities in these areas to justify its recovery, with the exception of a small quantity produced by the Carrock Mine in the early 20th century. The principal ore of arsenic is arsenopyrite, or arsenical pyrites (FeAsS), also known as 'mispickel' or 'white mundic' found in close association with copper and tin ores (Scrivener et al. 1997, 19). The geology of arsenic production is therefore firmly linked to that of tin and copper mining in Cornwall and Devon, addressed in the Resource Assessment for those metals.

12.3.2 Historical context

The first arsenic refinery in Cornwall was set up near Perranwell in 1817, to recover arsenic from mine waste. This was followed in 1835 by a second plant, again treating mine waste, near Bissoe-bridge, after which mine owners realised that what they were burning off as a contaminant was of value, and some began to erect flues to condense and collect the arsenic from their roasting hearths (Earl 1983, 12).

By the late 1860s, mines in Devon and Cornwall were working arsenopyrite specifically for the arsenic content, with sulphur (for sulphuric acid production) as a significant by-product. Within ten years production of arsenopyrite ores had risen to nearly 15 thousand tons per annum. Thereafter it fluctuated wildly but was still over 12 thousand tons of ore per annum in the last years of the century (Burt et al. 1984, xxv-xxvi).

The majority of the arsenic produced in Devon and Cornwall came from the treatment of tin and copper ores. Its production provided a significant supplementary income for many mines, but only in the case of Devon Great Consols, after 1884, did it become

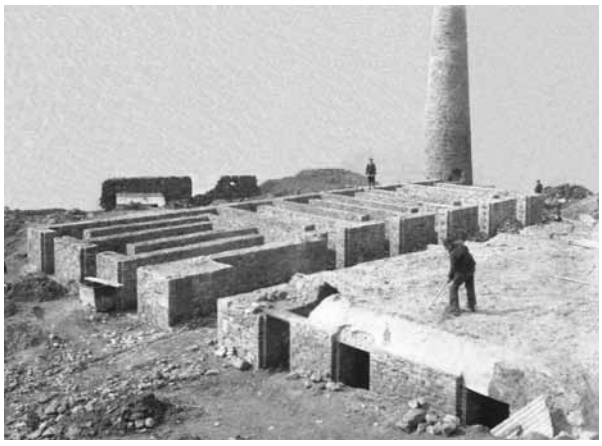

Figure 12.4 Arsenic flues attached to the calciner at Bottalack, St Just, under construction in 1907. © Pete Joseph

Figure12.5 The ruined flues and chimneys at Bottalack following conservation work in the 1990s. © Pete Joseph

Figure 12.6 The arsenic works at Devon Great Consols.
© Rick Stewart

the dominant source of income (Burt 1988, 23, Table 5). Although some arsenic production continued into the mid-20th century, it was at a very much reduced levels (Earl 1983, 26).

12.3.3 Technology

Arsenical ores were seldom sold in their raw state and needed concentration at or near the source to convert them into a commercial product. Earl (1983) provides a detailed account of the processes used in arsenic recovery and refining, and this might be used in the interpretation of surviving features, particularly those found on the later sites from the end of the third quarter of the 19th century.

The early calciners were simple structures, either reverberatory or shaft furnaces, sometimes modifications of existing 'burning houses', linked to long flue systems, in which the arsenious oxides would condense as soot of varying purity. From the 1830s onwards, mechanisation of the process was introduced with the water-powered Brunton calciner, which allowed for continuous operation. The Brunton, patented by William Brunton in 1828 (Stewart 2005, 10), had a rotating, convex, circular hearth, over which the flames from two fireboxes were drawn. Ore was fed into the centre of the hearth and was roasted as it slowly rotated below cast iron coulters, which ploughed it towards the outer edge where the fully calcined ore was discharged (Earl 1983, 15-17). Bruntons were usually associated with long flue systems, or labyrinths, in which the purified arsenic collected. Less successful, and less common, was the rotating tubular calciner developed by Oxland and Hocking in the 1870s, known as the 'Oxland Tube' and the adaptation of other mechanised hearths, which could allow pyritic ores to self-combust. However, the rolling motion of the ore in Oxland Tubes created too much dust and this system was less successful; the Brunton was, therefore, the foremost process used. The last Brunton calciners were in use up until the 1950s but, by then, the separation of arsenic from tin and copper ores was effected by froth flotation (Earl 1983, 24-27). Devon Great Consols had both Bruntons (by at least 1866) and Oxlands (by 1878) in use (Stewart 2005, 10-11).

Refineries, to which the arsenic-rich soot from the calciners was sent, were established, either at the larger mines or as separate concerns, initially part of the works recovering arsenic from mine waste. The earlier refineries employed cast iron retorts, or 'kettles', to separate out the arsenious oxide from the soot (Earl 1983, 13-14) but these were later replaced by flat-bed reverberatory furnaces, using high grade fuel such as anthracite, again linked to long flues and labyrinths or condensing chambers (Earl 1983, 19). Refined arsenic was then ground to a powder and packed in barrels for transport. The grinding mill from the 1920s refinery at Devon Great Consols survives.

12.3.4 Archaeological recording

The presence of arsenic in copper ores worked in Britain in prehistory may or may not be relevant to the production of arsenical copper and bronze; there is some evidence to suggest it may have been a factor in the selection of copper ores from Southwest England (Ixer & Pattrick nd), but it was not until the 19th century that arsenic bearing minerals were worked in their own right. It is therefore to the modern period, and to Cornwall and West Devon, that we look for the archaeological evidence for arsenic production.

Among the best preserved reverberatory calciners (burning houses) in Devon or Cornwall is one at the Atlas (or Albion) Mine, near Ilsington in Devon, Richardson (1992, 63). This has two burning chambers and an externally mounted stack, but it is unlikely to have produced arsenic commercially. A calciner of similar design, though with a single burning chamber, survives at South Devon United mines at Mary Tavy and this example has a long flue, added as a means of deliberately collecting the arsenic (P Newman *pers comm*).

The flues, labyrinths or condensing chambers, and associated chimneys of arsenic calciners are dominant features on a number of tin and copper mines in Cornwall and West Devon, and some of the sites identified by Earl (1983) have been stabilised and conserved, though others have now been lost through neglect or deliberate clearance. The Brunton calciners and associated labyrinth and flues at Levant, in West Cornwall, were recorded prior to remedial work which

resulted in the heavily contaminated site being covered over and the features are no longer accessible (Sharpe 1994). The similar surviving features at the nearby Botallack Mine in West Cornwall have, however, been conserved (Figs 12.4 & 12.5). They comprise the hearth for a Brunton calciner, flues, condensing chambers along with the remains of the stack; these have been surveyed and interpreted by Pete Joseph (2010, 179-91, and 2012), who had earlier prepared a survey and assessment of the calciner at Tolgus, in central Cornwall (2004).

On the Cornish side of the Tamar Valley, consolidation work on the surviving chimney at the Coombe Arsenic was accompanied by a report on the watching brief (Buck 2006b). The arsenic works at Okel Tor, Calstock, were included in the assessment of that mine (Buck 1999). Archaeological assessments have also been carried out at Devon Great Consols (Buck 2002), including the arsenic works, and on the Gawton works (Buck 2006a), both on the Devon bank of the Tamar; the latter being carried out as part of the Tamar Valley Mining Heritage Project. The arsenic works at both Devon Great Consols and Gawton had been the subjects of earlier archaeological survey work (Dixon et al. 1989; Pye & Dixon 1989; Pye & Weddell 1992).

Although the processes for the production of arsenic are well known, and many individual calciners have been recorded in Devon and Cornwall, no overview, analysis or inventory of the surviving buildings is known, and a comprehensive study is overdue.

12.4 Bismuth

12.4.1 Introduction

Bismuth is present in mineral deposits worked in Southwest and Northwest England, from the post-medieval period through to the late 19th century, but was only exploited on a very small scale. East Pool, in Cornwall, was the largest producer with an output of four tons, valued at £120, between 1872 and 1877 (Burt et al. 1987, xxxii). The metal was utilised in non-ferrous alloys used for a limited number of specialist purposes, including type metal where its characteristic expansion on cooling assisted in maintaining the form of the letters.

12.4.2 Geology

In Southwest England, orefield bismuth occurs as flakes of native metal in the cross-coursing veins, and is a weathering product of the sulphide ore, bismuthinite (Bi_2S_3). Elsewhere in that field it is either widely disseminated amongst other ores or as the sulphide in the lining of vughs within the veins (Dines 1969, 30). In the Northwest the sulphide appears to be linked to copper deposits (Bridge 1994) and, in the North Pennines, it is associated with enhanced silver levels close to the high temperature zone around the concealed Weardale Granite although, in the latter case, there are no records of production (Ixer et al. 1996)

12.4.3 Historical context

The first documentary reference to the extraction of bismuth in England comes from the accounts of the 'German' led operations to mine copper and silver-bearing ores in the Lake District of Northwest England, operations for which were based in Keswick. In 1569 those accounts record the carriage of 'hemispheres' of bismuth to London (Bridge 1994, 33). The source of that bismuth was investigated by Dave Bridge and placed in its historical context alongside the exploitation of copper ores at that period in his paper on 'The German

Figure 12.7 Smelting bismuth from Agricola's De Re Metallica 1556.

Miners and the Question of Bismuth' (Bridge 1994). Our knowledge of later working for bismuth ores is, however, limited to 19th-century production figures for the Cornish mines (Burt et al. 1987). There has been little, if any, research into the role minor minerals such as bismuth played in the economics of mining in the 18th and 19th centuries.

12.4.4 Technology

Mining of bismuth ores was carried out in connection with that for other ores and no special techniques were employed in its extraction. Initially native bismuth or its ores were probably manually separated during processing. Later, in the 19th century improved gravity separation during ore processing allowed minor minerals such as bismuth to be selectively removed but such techniques were not exclusive to any particular mineral.

The process of recovering the metal from bismuth ores was a form of liquation, a technique shared with other metals, such as antimony, which formed at low temperatures. Liquation was employed at Keswick in the 16th century to recover bismuth found in combination with copper ores. The technique would have been familiar to the 'German' miners and smelters from central Europe, employed at Keswick and it was illustrated by Agricola (Agricola 1556, 433-7). One characteristic of that technique was the collection of the unrefined metal in a hemispherical pot, as illustrated by Agricola, and those 'hemispheres' of bismuth feature in the documentary record for the Keswick operations (Bridge 1994, 33-34).

12.4.5 Archaeology

The extraction of bismuth, as with a number of other minor minerals, was carried out as a by-product of the mining of the major non-ferrous metals. No specific mining techniques were used which might identify bismuth mining in the archaeological record. Bridge (1994) has, however, identified those mines in the Lake District that were the likely source of the ores in the 16th century and some evidence for ore preparation may survive on site. The processing of bismuth and bismuth ores did entail specific techniques for which archaeological evidence, in the form of residues from ore preparation and smelting, is likely to survive but there have been no programmes of investigation which might have recorded that evidence and linked it directly to bismuth production.

12.5 Cobalt

12.5.1 Introduction

Cobalt is found as a component in mineralisation across the British Isles (Andrews 1962, 64; Tindle 2008). However, it has only been recovered at a few localities, principally in Cornwall, Cumbria and Cheshire, but also in North Shropshire, and the Ochil Hills, Scotland (Andrews 1962, 65). Once separated, cobalt minerals were used primarily in the manufacture of smalt, a pulverised glass produced by fusing cobalt oxide with powdered flint and potash, which was used for colouring in china and glass manufacture, and as a 'blue whitener' in paper making and in the linen industry. Ores could be smelted to produce the metal; this was usually carried out by specialist smelters remote from the mines, but in one case, in Cumbria, it appears to have been attempted on site.

12.5.2 Geology

In Cornwall cobalt minerals include smaltite (a variety of the arsenide skutterudite), the hydrated arsenate erythrite, the sulpharsenide cobaltite, and the oxyhydroxide asbolane (Tindle 2008), and are found in association with nickel and bismuth ores (Dines 1956, 30). The association in Cumbria is with copper-lead-zinc mineralisation and barite, with the former mineral grouping being linked to the Borrowdale granite intrusion (Stanley & Vaughan 1982). In Triassic sandstones of the Cheshire Basin cobalt is associated with barite mineralisation and localised occurrences of low grade, copper-dominated, sediment-hosted ore deposits, of which those in the Alderley Edge Geological Site of Special Scientific Interest are cited as a classic example (Warrington 2010).

12.5.3 Historical context

Saxony was, from at least the 17th century, a principal European source of cobalt but export of the ore was prohibited and it was roasted there to produce *zaffre* for export; the Duke of Saxony thus monopolised the source material and that product, from which *smalt* was prepared. The cost of importing *smalt* into England in the mid-18th century, stimulated a search for indigenous sources of cobalt ore. Some were already known from Cornish mines, and smalt production had been attempted there. In 1754 the Royal Society of Arts offered a premium of £30 for the best English ore sample, and this was awarded in 1755 for ore from a mine near Truro. In the same year the Society offered a premium of £30 for the manufacture of zaffre and

smalt from indigenous ore; this was not awarded until 1764 (Watney 1963). The Napoleonic Wars resulted in further impetus to the discovery of indigenous supplies amongst which were those in Cheshire (Warrington 1981a; *forthcoming*).

Only a few mines in England produced cobalt ores or concentrates. In Cornwall, East Pool, Great Dowgas, and St Austell Consols have recorded outputs, in the last case mixed with nickel ore (Dines 1956, 333, 545-46). Ore was raised from Trugo (Beer 1988, x) and parts of South Crofty (Dines 1956, 318), and possibly also from Dolcoath (Dines 1956, 30). Wheal Sparnon in Redruth was an important source of cobalt ore from at least 1808. Work there ceased in late 1810, but had resumed by 1814 when 'superior quality' ore was being produced; two tons, valued at £1200, were sent to London. Later, around 80 tons were raised in about one year from a 'large and valuable cobalt lode'. Mining at the 'Wheal Sparnon and Corner Stone Cobalt Mines' stopped while accumulated ore was smelted to produce pure oxide. A separate company was formed for that purpose and about £4000 worth of oxide was sold to potters between mid-1816 and mid-1817. In 1819 the 'cobalt lode' was worked down to 60 fathoms, and eventually down to 70 fathoms (below adit). In 1826, a 'cobalt works' was completed at the mine, which was then unique in Cornwall for being worked *solely* for cobalt ore. Sales of the product to Staffordshire were anticipated, and £600 worth of cobalt was prepared by January 1827, but the mine closed soon afterwards (Hamilton Jenkin 1962b, 19-23). Before 1817 some ore from this mine was refined by the British Cobalt Smelting Company at Hanley (Watney 1963, 8). Cobalt ore was evidently worked at the Wherry Mine in Mounts Bay (Russell 1949; Hamilton Jenkin 1962c) in the late 18th century; Williams (1810, 488 cited by Timberlake 2010) referred to the mineral worked as 'pure cobalt ore'; erythrite and skutterudite have been recorded (Tindle 2008, 200). Some ore was produced at Wheal Owles and Boscawen before 1893, and at Polgooth, Wheal Huckworthy and Wheal Unity (Andrews 1962, 65). Cobalt ores were recorded from the Botallack, Levant, Hawkes Point, Rosewarne and Herland, and South Terras mines (Dines 1956), and cobalt minerals are recorded from many others in Cornwall (Tindle 2008).

In the Lake District, cobalt ore was obtained from mines near Coniston (Andrews 1962, 65) and near Borrowdale. From about 1848 the Keswick Mining Company attempted to work cobalt at a mine high on the fells between Sail and Scar Crags, to the west of Borrowdale. The intention appears to have been to produce metallic cobalt. Dressing floors were erected and a smelt mill adapted for the purpose but the working failed without producing anything of value (LDNPA HER UID 11654; Postlethwaite 1987, 109; Adams 1988, 47-48).

In Cheshire, mines at Alderley Edge were leased to the Alderley Mine Company in 1805. Cobalt minerals, predominantly asbolane (a mineral of variable composition but usually including nickel, cobalt and manganese or 'wad'), were recognised there in 1806, after probably being first identified at nearby Mottram St Andrew. In 1808, the Alderley cobalt ore was let to Tomlinson, Plowes & Co. of the Ferrybridge Pottery, in Yorkshire. However, this agreement was terminated after little more than one year, although ore continued to be produced at Alderley and a treatment works was established at Wallasey, operated by the Seacombe Cobalt Company. That was dissolved around 1814 and succeeded by the Seacombe Smalt Company. However, the Alderley Mine Company had been dissolved before 1812 and the source of ore treated at Wallasey following that date is unknown. The Seacombe Smalt Company was dissolved in 1817 in the face of competition following resumption of imports from Europe after the Napoleonic Wars ended (Warrington 1981a; *forthcoming*). Cobalt was recovered at Alderley Edge later in the 19th century, as a by-product of an acid-leaching process introduced there in 1857 to treat copper ore. It was also mentioned as having been sold from the nearby Mottram St Andrew mine between 1860 and 1865 (Warrington 1981a, 65).

Cobalt minerals have also been recorded from Bickerton, West Cheshire (Carlon 1981) and from mines in North Shropshire, at Eardiston, Pim Hill and Clive; some ore was produced from the last (Dewey & Eastwood 1925; Shaw 2009). These occurrences are in deposits similar to, but smaller than, those at Alderley.

12.5.4 Techniques and Technology

There are few techniques, or any technology, specific to the extraction and production of cobalt minerals or the metal. During exploration of the Cobalt Mine at Alderley Edge, tools were found which had evidently designed for extracting asbolane from joints in the sandstone (Timberlake & Mills 2003). The ore, described as blue-black grains, similar to gunpowder, disseminated in red sandstone or lying in thin seams, was 'got out in thin pieces, and separated afterwards as much as possible from the stone; it is then packed into tubs and sent near Pontefract, where it is manufactured into smalt' (Bakewell 1911). Otherwise the techniques of mining were no different from other mining activity of the period. Ore preparation would have relied initially on manual separation and grinding, with gravity separation employed in the large dressing floors treating

polymetallic deposits, as in Cornwall. Unfortunately, little is known regarding the attempt to smelt cobalt on site in Cumbria.

Later in the 19th century, the Alderley Edge Mining Company Limited produced cobalt-rich residues between 1857 and 1864 as a by-product of an acid leaching process for the extraction of copper. Solutions remaining after precipitation of the copper by scrap iron, were concentrated by boiling in wrought iron pans, then sprayed over sand-covered tiles heated from below, in a furnace at dull red heat. Metallic oxides accumulated in the sand, and acid vapour and steam were conducted to a condensing tower. The resulting acid was recycled, but to little financial advantage, and this procedure was suspended until cobalt present in the sand could be recovered profitably. According to Timberlake and Prag (2005, 140), a cobalt and nickel precipitate was subsequently partially smelted in reverberatory furnaces. A company report (*Mining Journal* 1864, 153) mentions furnaces at the 'cobalt works' being stopped after 357 tons of precipitate that yielded 10 tons 11 cwts and 2 qrs of 'speiss' with an estimated value of £650 to £700 had been processed (Warrington 1981a; *forthcoming*). There is no record of further production of those materials and the works referred to were clearly ancillary to that for recovering copper. 'Cobalt Treatment Works' and a 'Cobalt Tower' are alluded to in Timberlake & Prag (2005), suggesting the existence of a plant dedicated solely to cobalt production; these were a part of a much larger operation to recover copper ore.

12.5.5 Transport and infrastructure

The transport of cobalt ores presented little difficulty. They were relatively small in quantity and could be expected to utilise the existing infrastructure. For example, the quantity of 'cobalt-bearing wad' (i.e. asbolane) produced at Alderley in the early 19th century has been estimated as between 50 and 300 tons (Timberlake & Prag 2005, 144). This would have been carried by packhorses, or horse-drawn carts, to a suitable point for transfer by canal or river to the works at Ferrybridge or Wallasey. In the 1860's, Alderley produce may have been transferred from carts to railway wagons in nearby sidings. Treatment was attempted on site in the Lake District, and was carried out at Wheal Sparnon, from where, in the early 18th Century, transport of the product to customers in, for example, the Staffordshire Potteries, would have been largely water-borne, by sea to river and canal systems.

The extraction and processing of the minerals did not continue on any one site for sufficient time for the establishment of dedicated settlements.

12.5.6 Archaeological recording

Workings connected with cobalt mineral extraction at Alderley Edge and in Cumbria have been explored and recorded (Johnson 1984; Adams 1988, 47-48; Timberlake & Mills 2003; DCC 2007; Norgate 2012; Carlon & Dibben 2012, 103-09). The Ferrybridge Pottery site was interpreted by Bidgood (1978).

At Alderley, evidence for a 'Cobalt Treatment Works', particularly an interpretation of soil geochemistry, is alluded to in the work by Timberlake and Prag (2005). The site of the 'Wood Mine cobalt works and associated mines' is now a scheduled ancient monument (Number 1020181) and the description of this site alludes to 'buried remains of metal ore processing works' and states that features related to cobalt production that will survive include 'remains of wooden tanks, … the bases of furnaces for heating the cobalt bearing solutions, the foundations of the cooling tower for evaporating the heated mixture and the beds for the steam engines which powered the entire process'.

Traces of some structures have been noted in this area (Timberlake & Prag, 2005), but none are unequivocally related to cobalt production which ended in 1864. Many, if not all, the structures erected by the Alderley Edge Mining Company Limited were removed after the company wound-up and its effects were auctioned in 1878 (Warrington 1981a; *forthcoming*). A small processing plant, that would have overprinted vestiges of structures from earlier periods, was erected on the site, and removed, in the early 20th century (Warrington 1981a; *forthcoming*). Some buildings contemporary with, and possibly connected with, the early-19th-century cobalt mining are extant but lie outside the area of the scheduled monument.

12.6 Jet

12.6.1 Introduction

Jet was formed by the coalification of individual trees, an ancient species of Araucaria, buried in Jurassic marine sediments. It is found on the escarpment of the Cleveland Hills and the valleys to the south, and is exposed in the cliffs along the coast of Northeast Yorkshire as far south as Whitby. It is believed to have been used for ornamental purposes for at least 4,000 years, particularly in the Roman period, and its popularity in the last half of the 19th century resulted in numerous small-scale mining operations. From the 1850s, to the present day, Whitby has been the centre for processing jet mined in the area, reaching its peak of production in the 1870s.

12.6.2 Geology

Jet is not found in regular seams, but is randomly distributed throughout bituminous Upper Lias shale, principally that known as the Jet Rock. This is up to 9m thick and lies between the ironstone strata above and freestone, called the Top Jet Dogger, below. The Jet Rock outcrops on the coast from Ravenscar to Saltburn, on the northern escarpment of the Cleveland Hills and in the valleys to the south. Jet found at that horizon is referred to as 'hard jet'. It was deposited as driftwood on a sea bed in anaerobic conditions, covered by later sediments and subject to compression leading to severe disintegration. At a higher horizon than the Jet Rock are other deposits, thought to have formed in a freshwater environment, which are not as compressed as those in the Jet Rock and are liable to cracking. These latter deposits are generally referred to as 'soft jet' and are not as attractive as the 'hard jet' for working into ornaments.

There are other potential sources of jet in England particularly in the Upper Lias beds of Leicestershire, where 'large masses of wood, converted into jet' were used as whetstones (Watts 1996, 24, citing Fox-Strangways 1903, 39). Jet is also, occasionally, found in the Upper Jurassic Kimmeridge shale of Dorset, and is found on beaches in Norfolk, but there is no evidence that these areas have been worked to the same extent as the deposits in the Cleveland Hills and around Whitby (Watts 1996, 24-25).

12.6.3 Historical context

Jet is believed to have been used for ornament for 4,000 years, and artefacts said to have been made from it have been recovered from Bronze Age burial mounds throughout England and Scotland (however, see below (Watts 1996) for discussion on the identification of jet in Roman and earlier finds, and its similarity to other black lithics such as cannel coal). The material was popular in the Roman period when Whitby jet was worked at a specialist centre at South Shields (Allason-Jones & Jones 1994; Allason Jones 2002). Nevertheless, it did not become popular in more recent periods until Queen Victoria endorsed jet jewellery on display at the Great Exhibition of 1851. After the deaths of the Duke of Wellington, in 1852, and Prince Albert, in 1861, the fashion of wearing jet during mourning gave the trade an annual turnover in excess of £90,000, and Whitby had over 1,500 employees in nearly 200 jet workshops, with the best carvers earning up to £4 per week by 1871.

While it was processed in Whitby, much of the jet was mined inland. For example, in 1871, Swainby had 38 miners, some of whom were locals, but others were unemployed ironstone miners (Vickers 1987). Agents, acting for the manufacturers, bought rough jet at the mines. It was then cleaned and sawn into blanks, of various sizes, from which jewellery was carved and engraved with beautiful designs on its surface using knives, chisels and gouges. Finally, the work was polished on oiled boards, and finished by 'rougeing' over a spinning disc covered with walrus hide. Smaller pieces of jet were used to make beads, and intricate detail was finished on a brush wheel.

In the mid-1880s, changing fashion and the use of alternative materials devastated the local trade. Jet is still worked in Whitby but primarily for the tourist trade. Most, if not all, the material used in that trade is the product of coastal erosion but some will no doubt come from illicit small-scale operations, reworking existing mines. See McMillan (1992) for a good account of jet working based on longstanding family involvement in the trade.

12.6.4 Technology

The extraction of jet in the prehistoric and the Roman period was most probably from outcrop deposits and beach finds as a result of coastal erosion. The exposure of jet in the cliffs north of Whitby was identified in documentation by at least the early 17th century (McMillan 1992, 18) but it was not until the 1850s that there was a concerted effort to work those deposits underground as the demand for jet dramatically increased. Initially this was done by individuals suspended on ropes and working the exposed jet deposits into the cliffs. A common reference in the documentation of the period, from the 1850s into the 1870s, was to the 'working of the jet cliffs ... by drifts' (McMillan 1992, 19, citing an advertisement in the *Whitby Gazette*, December 1868). The random nature of the jet deposits made this, and all other methods of extraction, not only dangerous but extremely speculative.

Jet mining always remained a small-scale operation, with one, two, or three men working a single drift or adit and its associated extractive face. In the inland areas, on the scarp and in the valleys to the south, drifts were driven at the base of the Jet Rock to the point where the shale became tougher. Known as the 'face', this was seldom further than 100m. One man drove the drift, using a fine-pointed pick, while a second barrowed the shale to the surface where a third sorted it to find pieces of jet ranging up to 13cm in thickness and 1.8m in length. By pulling down the drift roof to form a platform, it was possible to work upwards through the shale until the overlying Top Jet Dogger was reached. This took very little timber, used no explosive and relied on natural ventilation. The work was lit by candles.

12.6.5 Infrastructure

Beyond the jet workshops in the back alleys of Whitby, there is little in the way of infrastructure associated with the extraction of jet. The miners in the late 19th century lived within the existing settlements, some coming from an ironstone mining background. Jet, relatively light and valuable, required no specialised transport and used the existing road system. It was probably not stored on site after extraction and the huts sometimes found in association with the workings would have been for tools etc., rather than for secure storage of a valuable product.

12.6.6 Archaeological recording

Traces of jet mining can be seen in many valleys in the North York Moors National Park, and along the escarpment between Guisborough and Osmotherley. Collapsed drifts and their shale tips are regularly spaced around the hillsides. A few have the remains of miners' huts. In some cases the waste shale has been burned and removed for road building. The location of these workings has been recorded (David Pybus, *pers comm*) and a small number have been explored and surveyed (*e.g.* Ryder 1975 and 2002).

English Heritage's *Rapid Coastal Zone Assessment*, Project 3729, in its section on Whitby to Reighton (Buglass & Bingham 2008), identified a number of examples of jet working, all classified as being post-medieval to modern purely on location, documentation and typology. No investigative dating has been carried out. Jet beads have been found in a midden at the foot of the East Cliff at Whitby and a pendant found in a grave at the Chapel of Our Lady, Whitby, both in Early Medieval contexts, suggesting the probability of working at that period (Buglass & Bingham 2008, 148 and 184, citing the North Yorkshire HER). Beyond this, there has been little in the way of archaeological site investigation.

Watts (1992), in the investigations leading to her PhD thesis in archaeological science at the University of Bradford, has critically examined the identification of 'jet' artefacts from the Roman period. Her reassessment of 'black lithic materials' in Roman Britain has challenged some of the assumptions about the use and sources of those materials. She has shown that materials other than jet were used for many of the objects so classified from excavations at Verulamium, southwest of St Albans in Hertfordshire, and that the diversity of materials found in a Roman context at York suggest that not only jet was being carved there at that period.

For both Hawsker-cum-Stainacre and Fylingdales parishes there are recommendations for further investigation of jet workings (Buglass & Bingham 2008, 105-06), and that might be extended to all the known locations for working north and west of Whitby.

12.7 Manganese

12.7.1 Introduction

From the late 19th century onwards, manganese was used extensively in steel production as an additive to assist with removing sulphur and oxygen during the Bessemer process, and as an alloy that toughened the steel. Its deoxidising properties were also in demand for a number of other processes which predate its use in the steel industry. The addition of only a few kilogrammes per 1000 tonnes of manganese dioxide, or calcium manganate, to glass, removes the residual iron oxides found in some glass sands, which can discolour the finished glass. When used in larger quantities, the manganese could provide colour to the glass, from purple through to black. Other applications included its addition to oil based paints as a drying agent, as an oxidising agent in the manufacture of bleaches and dyes, and its use as a colorant in pottery glazes (Wilkie & Burt 1984, 19-20).

By far, the majority of the manganese ores mined in England came from the county of Devon but there are numerous other, lesser sources in Derbyshire and Warwickshire, which have contributed to production (for recorded production levels in the second half of the 19th and the early 20th centuries, *see* Burt et al. 1984, xxvii). After the late 1880s, production from English mines was eclipsed by that from mines in Merioneth and Carnarvonshire, in Northwest Wales. The latter are, however, outside the remit of this project but details can be found on-line (Linton nd.).

12.7.2 Geology

There are a number of manganese minerals which have been worked economically in England. Pyrolusite (MnO_2), manganese dioxide, at around 63% manganese, and rhodonite ($MnSiO_3$), a manganese silicate with around 42% manganese, along with psilomelane, a basic oxide of barium with manganese ($(Ba,H_2O)_2Mn_5O_{10}$) having a manganese content of 70-80%, have been worked in Devon. Rhodochrosite, also known as dialogite ($MnCO_3$), the manganese carbonate, was the principal ore worked in Northwest Wales, but was not of economic importance in England (Dewey & Dines 1923). An impure mixture of hydrous manganese oxides, known as 'wad', has been worked in Derbyshire and at Hartshill in Warwickshire. Manganese oxides are found in combination with cobalt and other minerals in

the sandstones on the rim of the Cheshire Basin, where they were also known as 'wad', but worked primarily for their cobalt content (*see* Section 12.5). Manganese oxides are sometimes found in combination with iron oxides, such as umber, the earth mineral pigment, worked in a number of locations in Devon, and across England (Beer & Scrivener 1982, 144-45; *see also* Section 11).

The manganese minerals described above are all secondary deposits and their origins in Devon are 'a matter of speculation'. They are much earlier than the Cornubian granite emplacement and are found as replacement deposits in chert beds and as cement in sandstones (Beer & Scrivener 1982, 143-44). The origins of the 'wad', impure deposits of manganese oxides mixed with iron oxides, worked in limestone of the Elton - Winster area, and the area north of Brassington, in Derbyshire are also unclear. They are discussed in detail by Ford (2006, 200-01; and 2001, 43-44) but appear to be secondary deposits derived from adjacent strata.

12.7.3 Historical context

The properties of manganese minerals as colorants and oxidising agents appear to have been known since antiquity, and they were probably first worked in Britain during the Roman occupation (Burt & Wilkie 1984, 20, citing Down 1980). From the Roman period through to the post-medieval the use of manganese minerals is primarily linked to glass production but it is not until the late medieval period that there is clear evidence for glass production in England (Crossley 2012; English Heritage 2011, 29). Prior to that, glass was largely imported from continental Europe, with some examples of manganese glass from the Near East turning up in Southeast England (Williams 1983).

There is, as yet, no evidence that English sources of manganese were used prior to the late 18th century and the development of mines at Upton Pyne, near Exeter in Devon (Russell 1968-70). There is documentary evidence to suggest that manganese was being worked in Warwickshire at the same period (Cook 2013, 2). The Upton Pyne mines had probably closed by the mid-1820s, but new workings had already been opened up a short distance to the north at Newton St Cyres and those were to continue in operation into mid-century. By that date, however, the focus of manganese mining in Devon, the only production area of any significance in England, had shifted to the Teign Valley and West Devon. Burt and Wilkie (1984) provide a comprehensive account of the development of manganese mining in Southwest England, which identifies the numerous small mines around Milton Abbot as being the principal source of manganese ores well into the mid-1880s, with the Chillaton Mine being by far the largest producer. A scatter of small mines in Cornwall, North Devon and Somerset also made a much lesser contribution to production (*see* Hamilton Jenkin 1969 and Claughton 1975 for detail on those lesser producers). Thereafter, they were quickly eclipsed by production from mines in North Wales, in the counties of Carnarvon and Merioneth (Burt & Wilkie 1984, 34; *see also* Linton (nd) and Down (1980) for more detail on the North Wales mines).

The requirement for manganese as a deoxidising and toughening agent in steel production from the late 1860s onwards, resulted in a wide search for suitable ores. The North Wales mines made a significant

Figure 12.8 Aerial view of the surface remains at Monkstone manganese mine in West Devon in 1928. Britain from Above © Crown Copyright

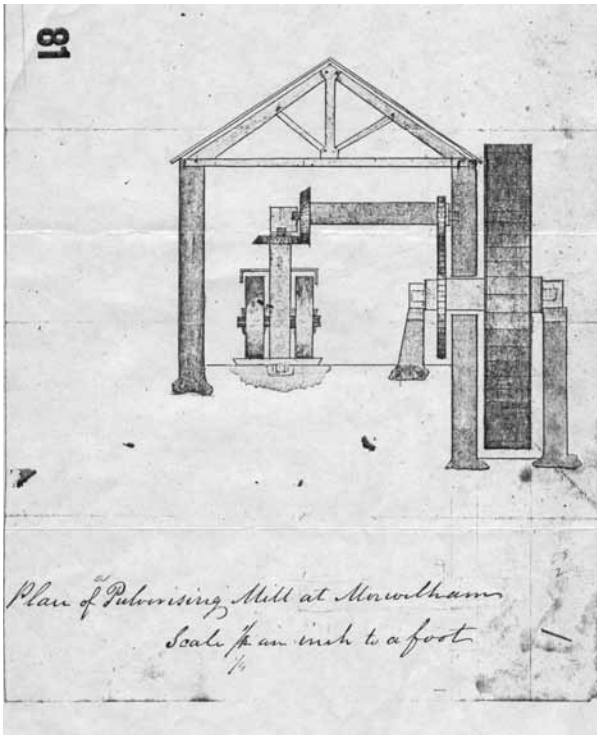

Figure 12.9 Sketch elevation of 1845 by I K Brunel of the water-powered pulverising mill at Morwellham Quay. Robert Waterhouse

contribution in that respect and, although, there was little expansion of manganese production in England as a result of the new demand, the Southwest did contribute significant amounts of manganese-rich iron ores; these came particularly from the Brendon Hills in West Somerset, and were used in the preparation of speigeleisen (containing 15-25% manganese) as part of the the deoxidising process (Burt & Wilkie 1984, 19; *see also* Section 5).

12.7.4 Infrastructure and technology

The mining of manganese was very small scale when compared with other mining operations in England and it placed no great demands on the country's industrial infrastructure. Short tramways were built to serve individual mines, as at Greystones Mine in East Cornwall, but the bulk of its transport needs were met by river and coastal shipping. Quays on the rivers Tamar and Exe were the shipping points, with Exeter the principal port used in the late 18th and early 19th centuries.

In much the same manner, the techniques of manganese mining drew on the wider technology of mining and ore dressing. One element which does, however, stand out in treatment of the ore is the establishment of preparation sites close to the shipping points, particularly on the River Tamar at Morwellham Quay (Waterhouse *forthcoming*) and at Slimeford, in Calstock parish. There the ore would be crushed and concentrated using gravity separation in water. In other parts of Southwest England, that preparation was carried out on the mine and dressing floors can be a significant feature, even on small mines like Fullabrook, near Braunton, in North Devon.

12.7.5 Archaeological recording

Little attention has been paid to the archaeology of manganese mining and its associated infrastructure. It features in the Rapid Identification Survey (RIS) for the parishes on the Cornish bank of the Tamar Valley where a number of small mines, including Greystones and Wheal Leigh, were noted along with some elements of the transport infrastructure at the former (Thomas & Buck 1994, 17, 22). Although surveys were recommended none appear to have been carried out.

However, surveys have recently been carried out on the sites of the manganese dressing mills at Morwellham Quay and at Shillamill near Tavistock (Waterhouse 2008a & 2008b). The manganese quarry at Hartshill Hayes, in Warwickshire, was included in a survey of the castle and its environs (Brown 1997) and underground workings close by, at Purley Chase, have been explored and mapped by Cook (2013).

12.8 Tungsten/Wolfram

12.8.1 Introduction

The presence of tungsten/wolfram in tin ores in Southwest England (Cornwall and West Devon) was, like arsenic, a major contaminant which, if it was not removed prior to smelting, seriously degraded the value of the metal. Its German name 'wolfram' is even derived from reference to its unwanted status - wolf's spit or froth (T Young *pers comm*[1]). It was not until the second half of the 19th century that the value of the metal as a hardening alloy in steel was realised, and at that period, methods of effectively separating tungsten ores from the tin were being developed. However, the processing of tungsten ores was a complex procedure, and the British metal industries showed little interest in producing it, preferring to send the concentrates to Germany for processing and re-importing the metal for use in the steel industry. With the advent of the First World War this reliance on German processing was curtailed; tungsten ores were in considerable demand for armament production and British industry had to develop its own facilities quickly. The rise and fall of production in Cornwall, West Devon and in Cumberland (the only other source of tungsten ores in Britain) was governed thereafter by periods of conflict.

12.8.2 Geology

The principal economic ores of tungsten or wolfram (the two names are interchangeable for the metal although the latter is frequently used to refer to the ores) are wolframite ([Fe, Mn] WO_4), a mixture of the tungstates of iron and manganese, and scheelite ($CaWO_4$), calcium tungstate. They are found in Southwest England in association with tin as stockworks in greisen mineralisation linked to the Cornubian granite emplacement (Scrivener & Shepherd 1998, 149-50; Beer & Scrivener 1982, 134-35). In the Northwest, on the southern slopes of Carrock Fell in what is now Cumbria, the mineralisation is associated with a granite-greisen outcrop of the Skiddaw Granite Cupola (Moore 1977, 7-8).

12.8.3 Historical context

Although a number of mines in Cornwall, including East Pool, South Crofty, Carn Brea, Tincroft and Clitters United, along with Bedford United in Devon (Brooks 2001, 107-30), produced tungsten concentrates as a by-product of tin production (some 4857 tons from Cornwall up to 1913 - Burt et al. 1987, xxxii), only a few mines in Southwest England have been developed primarily as tungsten producers; Cligga Head and Castle-an-Dinas, in Cornwall, and Hemerdon, in West Devon. The last, although sitting on one of the largest tungsten deposits in Europe, has a recorded production of only 31 tons since being opened up late in the First World War (Dines 1969, 688-89). Despite having significant investment in milling facilities in the 1940s and again in the 1970s it has been kept on 'care and maintenance' for the majority of its life. There is, however, active development currently underway on the site by a new company, Wolf Minerals, who anticipates full production by 2015 (Wolf Minerals 2014). Cligga Head was re-opened in 1938, having been worked in a small way prior to that date, and worked until 1945 in response to the high demand created by the Second World War, producing 300 tons of tungsten concentrates (Dines 1969, 457-59).

Castle-an-Dinas was by far the most important tungsten mine in Britain, with a total production of over 2483 tons of concentrates over its 40 year life (Brooks 2001, 137). Tony Brooks (2001) provides a comprehensive account of the mine, which was opened up in 1917 in response to war time demand. Apart from a brief period on care and maintenance in the 1920s, the mine operated until the decline in the price of tungsten after the end of the Korean War, with its most productive period in the late 1930s.

Carrock Mine, the only tungsten producer outside of Devon and Cornwall, was probably the first to be worked primarily for tungsten. It was tried initially as a lead/copper prospect in the 1850s and 1870s, but soon failed and then re-opened for tungsten in 1902, being taken over by the German run Cumbrian Mining Company in 1906. In 1913 British interests took over, and the mine was worked for the duration of the First World War, after which it was closed, and only re-opened in 1942 as renewed conflict increased demand for the metal. Despite government sponsored exploratory work, the mine did not go into production and was abandoned the following year. Further exploratory work was carried out in the early 1970s and a new mill erected, but the mine closed more or less immediately. Renewed interest in the late 1970s led to further exploratory work and the mill was reactivated, but only operated for a short period before it was closed in 1981 and dismantled in 1985 (Moore 1977; Cooper & Stanley 1990, 43-47).

12.8.4 Technology

The separation of tungsten ores from the tin ore cassiterite was difficult because the similarity in their specific gravities (wolframite 7.1 - 7.5, and cassiterite 6.8 - 7.1) limited the effectiveness of gravity separation. Although controlled crushing, using stamps, could result in the more friable wolfram ores being removed as slimes, it was at the expense of a portion of the tin, which went with it. Tin ore associated with tungsten ores was, therefore, avoided if at all possible (Brooks 2001, 5).

In 1844 the Oxland process was introduced as an effective method of removing unwanted tungsten from tin concentrates. The concentrates were first roasted with sodium carbonate, as a result of which sodium tungstate was produced and, as that is soluble in water, the tungsten could be removed by leaching. This process was replaced at the turn of the century by magnetic separation, which first separated out any iron oxides from the concentrate using low power magnets, then removed tungsten minerals with high power magnets, leaving a clean tin concentrate. The tungsten ores thus separated were pickled in acid to remove any remaining iron, dried and then passed through another magnetic separator to produce a clean tungsten concentrate (Brooks 2001, 5-6). The mill at Castle-an-Dinas used a combination of crushing, gravity separation and magnetic separation, and is described in detail, illustrated with a flow sheet, in Brooks 2001 (38-44).

The mill erected at Carrock Mine in the 1970s and the trial plant at Hemerdon in the 1980s were probably the most advanced ore preparation plants erected in Britain which did not rely on flotation.

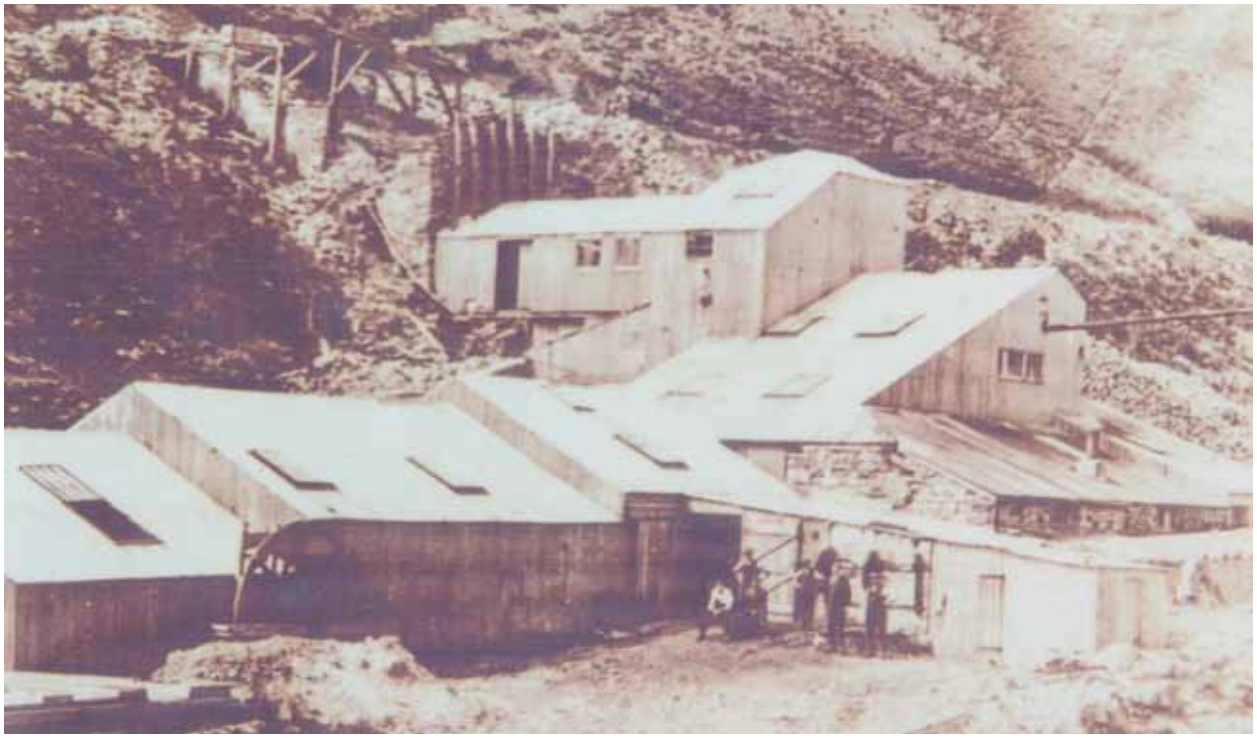

Figure 12.10 The Carrock Mine tungsten mill in operation during the First World War. © Warren Alison

12.8.5. Infrastructure

Prior to the first decade of the 20th century, the production of tungsten concentrates came as a by-product of tin production and was, thereafter, a relatively small scale specialist operation, only viable during periods of conflict. It placed no new demands on transport systems or settlement patterns.

12.8.6 Archaeological recording

Until recently, there have been no archaeological investigations embracing the physical evidence for tungsten mining. The Castle-an-Dinas mine was included in the Archaeological Survey Report (Bishop 2011), but only where it impacted on the Iron Age hill fort; the mine itself was not surveyed.

Two factors in recent years have focused attention on the archaeology of tungsten mining in Devon and in Cumbria. In the first instance, the renewed interest in exploiting the deposits at Hemerdon has initiated an assessment of the surviving features, including the mill buildings, but the results of that work have yet to be published. At Carrock Mine, concerns over the environmental impact of mine water discharges have resulted in remedial work, including stabilisation of one of the mine entrances, and on-going management of the scheduled ancient monument by the Cumbria Amenities Trust Mining History Society; this work was supported by an archaeological survey carried out by Archaeo-Environment Ltd (2012). In its turn, that has highlighted the condition of the early-20th-century mill buildings, which will to be surveyed prior to conservation work (John Hodgson, LDNPA archaeologist, *pers comm*[2]).

12.8.7 Notes on associated minerals

Nickel was mainly produced in Scotland, the only Cornish mines to market this mineral were Fowey Consols and St Austell Consols. During the 1850s and 1860s, they had a combined output of 17.6 tons of ore valued at £653. (Burt et al., *in prep*). Two tons of 50-60% nickel ore were raised from Pengelly mine (Beer 1988, xiii). Precipitates containing nickel were smelted at Alderley Edge for a short period (*see* Section 12.5.4).

12.9 Uranium ores and other radioactive minerals

12.9.1 Introduction

Uranium was first identified in 1789 and within fifteen years its ores had been found in Cornwall, the only part of England where they have been worked commercially. A small number of mines attempted to extract the ores but only two produced significant, albeit small, quantities. Although uranium has had an important role

in weapons production and power generation from the mid-20th century onwards, it was of limited economic value prior to the 1940s. Pitchblende (uranium oxide UO_2) was used as a glass colorant but some other uses for radioactive minerals, for example, the perception that they had health giving properties, were of dubious value. Marie Curie apparently, however, did isolate radium from pitchblende produced in Cornwall and this led to renewed interest in radioactive minerals in the early 20th century.

12.9.2 Geology

Uranium ores, primarily in the form of the oxide, pitchblende (UO_2), and alteration products, including autunite (calcium uranite) and tobernite (copper uranite), are found in the low-temperature, late phase mineralisation in Cornwall. It is generally associated with lead/zinc mineralisation but is also found in association with copper, as at Wheal Trenwith (Dines 1969, 29-30; 118-18; 541-43).

12.9.3 Historical context

The presence of uranium ores was well known prior to the late 18th century, when they would have been regarded as a contaminant, particularly in copper ores. It was not until the early 19th century that they were worked in their own right, being used to impart a green-yellow colour in glass production for which they were largely exported to central Europe. Two mines, South Terras or Union near St Stephen and Wheal Trenwith near St Austell, were the primary producers with Wheal Owles, East Pool and St Austell Consols also selling small quantities. After radium was identified as a separate element, present as a product of radioactive decay in pitchblende, with industrial and research applications, there was increased activity at South Terras and Wheal Trenwith and the dumps there were reworked to recover ores previously discarded as waste (Dines 1969, 118-18; 541-43). Smale (1993) provides a comprehensive historical account of the South Terras Mine but detail on the other mines is largely limited to that provided by Dines (1969).

12.9.4 Technology

Most, if not all, the ores produced in the 19th century will have been hand-picked on the dressing floors but a dedicated processing plant was installed at South Terras by 1922. Few technical details are available on the working of the plant. In 1928 a laboratory was established in Trevarthian Road, St Austell, and at least 100 milligrams of radium bromide were produced (Smale 1993).

12.9.5 Archaeology

South Terras Mine has been designated a Site of Special Scientific Interest (SSSI) on the grounds of the range of radioactive minerals found on the site but there has been no archaeological designation nor has there been any archaeological investigation of this or any other of the sites producing radioactive ores.

Notes

1. Tim Young, *Wolf's spit: new evidence for an old term*, presentation to the Historical Metallurgy Society meeting on Research in Progress, Newcastle University 6 November 2012.
2. Based on discussion at the Lake District Mines Forum meeting, Kendal, 31 January 2013.

Acknowledgements

Thanks to Warren Allison, Mike Gill, Phil Newman, Simon Timberlake, Geoffrey Warrington, Robert Waterhouse, Dave Williams for additional information and comment. The alum assessment is based on material compiled by David Pybus, and Peter Jackson. Additional information supplied by Ivor Brown, Mike Gill, Marcus Jecock, Adam Russell and Geoff Warrington. The jet assessment is based on initial notes compiled by Mike Gill and a PowerPoint presentation prepared and supplied by David Pybus.

13 Salt and other Evaporite Minerals

Peter Claughton

13.1 Introduction

The following minerals are covered in this section:

- Anhydrite ($CaSO_4$ - calcium sulphate); converts to gypsum under influence of ground-water
- Celestine ($SrSO_4$ – strontium sulphate); also 'celestite' in literature
- Gypsum ($CaSO_4 \cdot 2H_2O$ - hydrated calcium sulphate); includes 'alabaster'
- Halite (NaCl - sodium chloride); also 'rock salt' or 'salt'
- Polyhalite ($K_2Ca_2Mg(SO_4)_2 \cdot 2H_2O$ - hydrated potassium-calcium-magnesium sulphate)
- Sylvite (KCl – potassium chloride)

See also Tindle (2008) for descriptions of these minerals and their occurrences in England.

Halite has been mined as rock salt since the late 17th century, having been discovered during exploratory shaft sinking for coal at Marbury near Northwich, Cheshire, in November 1670. Prior to that, brine springs in Cheshire and at Droitwich, Worcestershire, and elsewhere were, with the output from a large number of coastal sites using seawater, the source of salt produced by evaporation. Alabaster, a fine grained form of gypsum, has however been quarried in the East Midlands for use in sculpture since at least the 14th century (Cheetham 1984, 11-13) and the use of gypsum for making plaster dates from about the same period. Production of anhydrite, celestine and the potassium salts began comparatively recently.

13.2 Applications and consumption

The expansion of mining and quarrying for salt and the other evaporites came in the 19th century with the development of the chemical industries. Halite was a feedstock for the production of the chlorine used in many chemical processes (Notholt & Highley 1973, Fig 8) including the production of caustic soda (sodium hydroxide) and soda ash (sodium carbonate). Halite (rock salt) was first mined at Winsford in Cheshire in 1844. This is now the site of the only remaining active rock salt mine in England, although some halite is produced as the result of development work at the Boulby potash mine in Cleveland. Production at Winsford expanded in the late 19th century to feed, together with brine produced from the Northwich salt fields, the chemical industry in North Cheshire (Male 1958a; Gregory et al. 1953). In Lancashire, halite deposits were discovered around Fleetwood and Preesall in 1872, during boring in search of hematite (Landless 1979, 38) and were a key to the development of the chemical industry in that area. Anhydrite mining was generally a much later development in West Cumbria, the Vale of Eden, and on Teesside, where it again fed a developing chemical industry (Hill & Clemo 1949; Semmens 1970). It was used extensively in the production of sulphuric acid.

Potash, a generic term for a number of potassium bearing minerals including polyhalite and sylvite, was discovered at depths of 800 to 1300 metres below the east coast of Yorkshire in 1939 by the d'Arcy Exploration Company whilst drilling for oil (Woods 1973), but was not worked until the mid-1970s at the Boulby Mine, where shaft sinking began in 1968. Currently, another mine is proposed to work south and east of the Boulby Mine. The vast proportion of output, peaking at more than 600,000 tons per annum in the late 1990s to 2003, is used in the production of fertilisers.

Celestine was worked from the late 19th century through to 1994 by shallow quarrying (only a few metres below surface), principally in the Yate area in South Gloucestershire, but also farther south, in Somerset (Sherlock & Hollingworth 1938; Thomas 1973; Nickless et al. 1976; Ball et al. 1979). It was used initially in sugar refining but subsequently other applications were found as a colorant in pyrotechnics and in the electronics, glass, ceramic, paint and other industries (Thomas 1973; Lane and Hardwick 2013).

13.3 Geology

Evaporite deposits in England are of Permian, Triassic, and to a lesser extent, Jurassic age (Highley et al. 1996).

In Permian successions they occur in formations of the Zechstein Group in eastern England and in deposits of equivalent Late Permian age in Cumbria (Ruffell et al. 2006). Gypsum, anhydrite, halite and potash minerals occur in eastern England but, apart from one record of halite (Worley 2005), only gypsum and anhydrite occur in Cumbria. In Triassic successions, gypsum, anhydrite, halite and celestine occur in the higher part, the Mercia Mudstone Group, with gypsum and anhydrite present in both the Sidmouth Mudstone and the higher Branscombe Mudstone Formations of that Group; halite is present almost exclusively in the former and celestine only in the highest part of the latter. The only evaporite exploited in Jurassic rocks in England is gypsum, in the youngest (Purbeck) beds in Sussex (Highley 1976; Highley et al. 1996).

These deposits result largely from evaporation of water of marine origin in partially or, at times, totally enclosed basins, and in bordering dry plains or sabkhas (e.g. Warrington 1974a), though some may have resulted from re-deposition by wind action (Morrison 2005). Deposits which formed in water often show a repeated sequence of minerals, indicating cyclic conditions with the mineralogy determined by solubility. The sequence, in which the most important minerals precipitate as evaporation proceeds, starts with the least soluble (carbonates: aragonite, calcite and magnesium carbonates) and progresses through gypsum and anhydrite to halite and those, such as polyhalite and sylvite, that are most soluble (*Encyclopaedia Britannica*).

Calcite ($CaCO_3$ - calcium carbonate) occurs as an evaporite in many parts of the world, but in England the only deposits which have been worked commercially are of hydrothermal origin and are therefore considered in the assessment for gangue minerals (Section 11).

Gypsum and anhydrite occur in beds or veins, or as nodules in Permian and Triassic rocks in eastern and northwestern England, through the Midlands and into the Southwest. In Permian successions they occur in the St Bees area, West Cumbria and the Vale of Eden, East Cumbria (e.g. Arthurton et al. 1978) and in eastern England, from Co. Durham southwards through Yorkshire (e.g. Smith 1974). In the Triassic these minerals occur in formations of the Mercia Mudstone Group, from Lancashire in the Northwest and Teeside in the Northeast, southwards through the Midlands and into Southwest England. The main exploited developments are in the Branscombe Mudstone Formation, in the upper part of the Group. In the East Midlands (Firman 1964), these occur at two main levels in that formation. At the lower level, the Tutbury Gypsum is worked in the west (e.g. in Fauld Mine) where it is a single bed up to 3.5m thick; this passes eastwards into a poorly developed nodular deposit (Taylor 1983). At the higher level, the Newark Gypsum comprises several beds in 15 -18m of strata (Barnes & Firman 1991; Howard et al. 2009). In the Trent valley to the south of Derby (Trafford Wynne 1906-7; Smith 1919; Edwards 1966), and at a few locations in Yorkshire and Staffordshire, the Tutbury Gypsum and its equivalents are fine grained and found in masses suitable for extraction as alabaster for sculpture.

In the south of England, from East Sussex across to Dorset, gypsum is found in strata of Jurassic age (Sherlock & Hollingworth 1938, 10-24; Firman 1984; BGS 2005, 4-5). In Sussex the Mountfield Mine opened in 1876 and production at the Brightling Mine

Figure 13.1 The Hawton Gypsum Quarry alongside Bowbridge Lane, Hawton in 1933. Britain from Above EPW041605. © Historic England

commenced in 1963 (Lake & Shephard-Thorn 1987, 58).

The principal celestine occurrences, around Yate in South Gloucestershire, may be diagenetic in origin, after gypsum or anhydrite (Nickless et al. 1976). They occur in the Mercia Mudstone Group at a similar horizon to the Newark Gypsum, and in Carboniferous rocks.

The most important halite resource presently worked in the country is in Cheshire and North Shropshire, in the lower (Sidmouth Mudstone) formation of the Triassic Mercia Mudstone Group in the Cheshire Basin (Plant et al. 1999). The extent of this resource was not appreciated until as recently as 1960, when a Geological Survey borehole at Wilkesley, in the southern part of the basin, proved the halite to be in two distinct units with a total thickness of 1,952 feet (595m) at that site (Pugh 1960). On Walney Island, Cumbria, and in the Fylde district of West Lancashire, halite occurs in thinner units at several levels in the Sidmouth Mudstone (Wilson 1990; Wilson & Evans 1990); these extend offshore, under the East Irish Sea. In eastern England, Staffordshire, Worcestershire, and Somerset (Notholt & Highley 1973) one halite-bearing unit occurs in that formation. Halite also underlies *c.*1200 km^2 of Dorset (Lott et al. 1982; Barton et al. 2011, fig.4c) where, though developed largely in the Sidmouth Mudstone, it may also occur in the lower part of the Branscombe Mudstone (Howard et al. 2008); it has not been worked in that area.

In eastern England, halite occurs in the upper part of the Late Permian Zechstein Group from Teesside southwards, through eastern Yorkshire into North Lincolnshire (Smith, 1974, 1989; BGS 2006a, 4-5).

Halite present in the lower part of the Triassic Mercia Mudstone Group in eastern England (Warrington 1974b; Riddler 1981) is in continuity with the extensive Röt Halite offshore to the east, in the North Sea Basin.

Polyhalite is found as a component of the Permian halite beds in East Yorkshire, where exploration work is underway with a view to exploiting it as a source for fertiliser production (Rowley 2012; Sirius Minerals nd).

Sylvite is found in association with halite in the Permian potash beds in East Yorkshire. The principal bed, the Boulby, which is on average 7m in thickness, overlies a halite bed with a total thickness of around 40m. A second bed, the Sneaton, overlies the Boulby but is currently not considered of economic value (BGS 2011, 3-4).

13.4 Historical context

Salt has been in constant demand in England for preserving food, and there has been continuity in production from Roman times through the medieval period to the present day. All the coastal counties of England had salt works, or 'wiches', designed to capture seawater at exceptionally high tides. The resulting salt-rich sands were then washed to extract brine which was evaporated in pans, using wood or peat as fuel, to recover the salt.[1] . In addition to the coastal resources, salt was obtained from natural brine springs derived from halite-bearing rocks through the dissolution of the halite by circulating ground water in the exposed salt beds or "Wet Rock Head" zone (Taylor et al. 1963, 78-79; Evans 1970). These were in Cheshire, around the town of Northwich, at Droitwich in Worcestershire and at localities in Shropshire, including Whitchurch (Stamper 1985), and in Staffordshire (Sherlock, 1921). Unlike coastal salt works, which were an intermittent operation governed by exceptionally high tides, the inland salt producers could continue throughout the year. The brine springs and evaporation pans at Droitwich were referred to in documents from the 7th to 10th centuries, as were the routes by which the salt was traded to a wide area in the west and south-west of England and were, judged on the revenues itemised in the Domesday survey, the major source in the 11th century. Upwich, one of the principal brine springs at Droitwich, has provided archaeological evidence for continued production from at least the Roman period through to the late medieval. Many inland manors had rights to salt works on the coast as had manors remote from the inland salt-producing areas. Such was the importance of salt to the economy of the period that rights around Droitwich, with five springs supporting over 300 salinae or saltworks, included not only manors within the immediate area but some as far afield as South Gloucestershire and Buckinghamshire. The construction of salt boiling / evaporation pans was a significant usage of lead, and they were sometimes referred to as plumbi (Claughton 2011).

The inland brine springs were evidently enlarged into sizeable pits and continued to be exploited through and beyond the post-medieval period (e.g. Ridgway 1958; Male 1958b). It was not until the late 17th century that deep shafts were sunk to directly exploit the salt-bearing strata. A sequence of rocks subsequently referred to as the 'Top Rock', or upper halite, which was later found to be in the lower of the two thick halite-bearing units in Cheshire (Pugh 1960), was found by chance in November 1670 at Marbury near Northwich, in Cheshire, during exploration for coal and was worked until 1781. Those workings were, however, unstable, as the percolation of ground water dissolved the salt and led to collapses in the ground above, with consequent flooding of the workings. A lower bed, the 'Bottom Rock', was discovered at Lawton, near Sandbach, in 1779 and, in 1781, at Marston, Northwich. By working the lower bed it was possible to reduce the inflow

of ground water, as the deeper workings were below intervening mudstones, and under the 'Dry Rock Head'. Until the mid-19th century, the mining of rock salt was confined to the area around Northwich, where working continued until March 1928 before finally ceasing when the Adelaide Mine collapsed and flooded. In 1844, mining began at Winsford, continuing on a small scale until 1892. From about 1888, salt was also discovered and worked on a small scale at Middlewich using shafts. After the collapse of the Adelaide Mine in 1928, the Meadowbank Mine at Winsford was reopened and is currently the only operational salt mine in England (Rochester nd - Rock Salt; Sherlock 1921, 55-58). 'Bastard brine' was also pumped from abandoned and collapsed mines, and from brine wells sunk specifically to exploit 'natural brine' in un-mined areas across the Cheshire saltfield (Wharmby 1987, 30-31). Pumping in this manner did, however, lead to severe subsidence and ground collapse problems, until the technique of 'controlled pumping' (below) was introduced into Cheshire in the early 20th century. Controlled pumping was carried out as far northwest as Agden near Lymm, north of the Warburton fault (Lymm.com 2012).

Rock salt was discovered at Stoke Prior, Worcestershire, in 1828, at Middlesborough in 1863, at Preesall, Lancashire, in 1872, at Walney Island, now in Cumbria, by the 1890s, in Staffordshire around 1881 (Sherlock, 1921) and at Puriton, Somerset, in 1910 (McMurtrie 1912; Whittaker 1970). Only in the case of Preesall was the salt mined. In Worcestershire, Staffordshire, Somerset and at Walney Island it was exploited by means of wells and extracted as brine;[2] at Preesall shafts were sunk to the halite deposits and brine that accumulated down-dip in the workings was pumped to the main shaft and then to the surface. During the first three decades of the 20th century, pillar-and-stall mining was carried out (Landless 1979) and was followed by a return to brine-pumping; Wilson and Evans (1990, pl.16) illustrated a part of the pillar-and-stall workings. From 1892 a new technique ('controlled pumping') was introduced at Preesall; water is pumped down a pipe within a borehole to dissolve the halite and the resulting brine allowed to flow to surface. In a development of this process, compressed air, or oil, was introduced to effect roof-control. Once the cavity formed reached an optimum size, extraction was moved to a new site about 180m distant and, by this means, stable cavities were created which did not result in surface subsidence. Under later management by Imperial Chemical Industries (ICI) the technique was also used in Cheshire and on Teesside (Notholt & Highley 1973, 18; Landless 1979; Morrison 2005)

Surface subsidence above the salt deposits in Cheshire had been a long standing problem since mining commenced in the 17th century. It was reduced by mining the lower halite bed or 'Bottom Rock', but once mines had flooded it was possible to continue extracting brine by pumping. As the brine was replaced by fresh water from surface, there was rapid dissolution of the surviving salt pillars in the abandoned mines, resulting in instability and the collapse of large areas of the surface including urban areas particularly in Northwich (Ward 1900; Calvert 1915; Rochester 1985).

Gypsum, particularly in the form of alabaster, was the only other evaporite which was worked to any extent before the 19th century. In fact, the quarrying of alabaster commenced in at least the 12th century when it was used in the construction of the west door to the priory church at Tutbury, Staffordshire, in about 1160 (Cheetham 1984, 12); its first use in the sculpture of ecclesiastical images dates from around a century later, Although documentary evidence for alabaster sculpture is largely confined to material originating in the East Midlands (around Tutbury and Chellaston), it is very likely that it was also quarried in other areas of England. Fine grained gypsum suitable for use as alabaster is found near Kingston-upon-Soar (Nottinghamshire), in small deposits in Purbeck (Dorset), at Ledsham (Yorkshire) and perhaps near York itself, where there are references to men employed in the alabaster trade in the 15th century (Cheetham 1984, 12-13). In the last case, its status and position on a navigable river meant that high grade material might have been imported coastwise from the Midlands. Firman (1984; 1989a and 1989b) provides a useful critical account of the sources of alabaster for sculptural purposes in the medieval and post medieval periods.

Buttercrambe, near York, was one of the sites documented as producing gypsum in the medieval period for calcining in the preparation of 'Plaster of Paris', used in York Minster. Other sites, including Purbeck, are known to have been exploited for plaster production from at least the 14th century (Salzman 1923, 100). By the 19th century, wherever gypsum of suitable quality was found it would have been quarried and calcined for plaster and, later, the manufacture of plasterboard. It was also used in the manufacture of Portland Cement. In 1938 the Geological Survey listed over 45 mines and quarries in Cumberland, Derbyshire, Leicestershire, Nottinghamshire, Somerset, Sussex, Westmorland and Yorkshire, all working gypsum in some form (Sherlock et al. 1938). In 2006 there were five mines and one quarry still working for gypsum (BGS 2005).

The mining of anhydrite, the anhydrous form of calcium sulphate, is a relatively recent 20th century development. Anhydrite was rejected by miners working for gypsum because it was unsuitable for plaster production, and it was not extracted in any quantity

until a use was found in inorganic chemical processes. Even as late as 1938 there was only limited exploitation, primarily in County Durham (at Billingham and, earlier, from 1924 to 1930 at the Warren Mine at Hartlepool) as a feedstock for the production of ammonium sulphate and in the manufacture of sulphuric acid, with small amounts being used in developments in plaster production (Sherlock & Hollingworth 1938, 8-9). A rise in anhydrite mining came after the Second World War. With increased demand for sulphuric acid, a new mine was opened up in Cumbria at Sandwith near Whitehaven (Anon 1961). The Long Meg Mine in the Eden valley, which had produced small quantities of anhydrite in the 1920s, was brought back into production (Tyler 2000), and the Billingham Mine continued in operation until 1971.

Potash mining in England is very much a post-war industry. The only mine in operation, at Boulby in what is now Cleveland, was not opened until 1968. Prior to that date the source of potash, along with other components used in fertilisers, came from mines on the continent or from 'natural resources'- primarily guano - whilst potash for use in soap production was produced by burning wood and other organic material. With the Boulby Mine in full operation from the early 1970s, England has become a major producer of potash for use as fertiliser and a new mine is proposed to work the undersea polyhalite deposits to the south and east of Boulby (Sirius Minerals nd). The Boulby Mine drives its underground roadways in the halite beds below the potash. Therefore, it is also producing rock salt as a co-product, which, in general is used for highway de-icing (BGS 2011, 5; Rowley 2012).

Although strontianite ($SrCO^3$ - strontium carbonate) is found as a gangue mineral in a number of lead mines in the North Pennines, it has never been worked commercially and is not an evaporitic mineral. Celestine has, however, been quarried in the Triassic Mercia Mudstone Group of Gloucestershire and Somerset. A large number of shallow pits were worked in the area around, and to the north of Yate in South Gloucestershire, from the late 19th century through to 1994 (Sherlock 1938; Thomas 1973; Nickless et al. 1976; Ball et al. 1979; Benham et al. 2006; Lane & Hardwick 2013). The location of some of those pits was mapped by the Geological Survey in the inter-war period when they were operated by the Bristol Mineral and Land Company (Sherlock 1938, 84); all the former celestine workings in Gloucestershire were recorded by Benham et al. (2006). Working in Somerset appears to have been confined to an area west of Regilbury Court, near Winford, where disused pits of unknown date were recorded, at Leigh Court, at Abbots Leigh to the west of Bristol; operations there were large enough to justify a tramway to the River Avon before working ceased around 1912. Other workings were to the south of the Mendip Hills, near Westbury and North Wooton (Sherlock 1938, 87-88; Thomas 1973, fig.1; Nickless et al. 1976, fig.2).

13.5 Techniques and technology

Early mining of salt and the quarrying of alabaster relied to a great extent on manual labour, as at Fauld mine (Trafford Wynne 1906-7, figs 8, 10-12), but from the 19th century onwards, as the extraction of salt and the other evaporites expanded, there was widespread mechanisation. Extensive use has been made of wheeled / trackless vehicles underground in the working of gypsum, anhydrite and potash. Currently, continuous mining machines are used underground in the extraction of gypsum and potash. The late development of large scale underground extraction meant that most mines utilised drainage by electric pumps, although some of the earlier salt mines used steam powered pumps from 1788 onwards for both drainage and brine pumping (Rochester nd - Rock Salt, 2). The techniques employed in shaft-sinking at the Boulby mine around 40 years ago were described by Cleasby et al. (1975).

Solution mining techniques, as first used in salt extraction, caused extensive surface instability but that was overcome by the use of 'controlled brine pumping', developed at Preesall in Lancashire and transferred to other salt fields under ICI management (Notholt & Highley 1973, 17-18; Landless 1979; Morrison 2005). In the 1950s and 60s, solution mining, using controlled pumping, was also tried on an experimental basis by ICI for the extraction of potash at Upgang and Aislaby, now in North Yorkshire; documents relating to the installation of the pipelines are deposited in the National Archives (TNA:PRO BT 356/10262 and 10263).

It was in the processing of salt that techniques unique to the industry were developed. From the Roman period onwards, lead pans were used for the evaporation of brine to produce salt. In in the post medieval period, these were replaced by larger iron pans, heated by coal rather than wood fires, and they continued to be used on a large scale right through into the 20th century. Large 'salt works' were established close to the point of extraction, producing a range of salts for various uses. Some halite was also sent to salt refiners on Merseyside and, from the early 19th century onwards, used as a feed stock for new processes, such as the production of alkali by the LeBlanc process, on Merseyside, Tyneside and Clydeside (Rochester nd - Growth).

The real advance in the evaporation of brine to produce salt came in the 1890s with the application of vacuum evaporators to salt production. Considerable

savings in fuel over the open pan method was the driving force behind the adoption of vacuum evaporation, which is still used today. Large plants were constructed at Winsford and at Runcorn, in North Cheshire, fed by brine pipelines (Morrison nd). Some 'salt works', such as the Lion Salt Works at Marston, Northwich, continued to use the open pan methods right up until closure in 1986 (Fielding 2005).

Processing of gypsum for cement, as mineral white or for the plaster trade, also required specialist plant that was generally located close to the point of extraction. Gypsum rock, crushed and ground using French buhrstones or Derbyshire millstones before going for use in plaster, was calcined in what were referred to as 'kettles' or 'boiled' in 'pans'. Sherlock and Hollingworth (1938, 27) illustrated a flow sheet for the Cocklakes Mine in the Eden valley, Cumbria, which provides a useful explanation of the processes at that period; the grinding processes were reviewed by Fitzgerald (2011, 136-38)

13.6 Transport and infrastructure

In the medieval and later periods, pack horse routes linked the inland salt producing areas to their markets (*e.g.* Houghton 1932). There was a similar reliance, at least in part, for the transport of alabaster, worked and unworked, in the late medieval period. River and coastal shipping was, however, the most economic method of moving bulky cargoes of salt and alabaster and this was facilitated by the close proximity of extraction points to the river system in England. The alabaster quarries in the East Midlands were located close to the River Trent. In Cheshire, the transport of rock salt was improved when the River Weaver was made navigable (Robinson 1958; Rochester nd - Rock Salt, 2). The Weaver Navigation Bill was passed in 1721, but the actual Weaver Navigation canalised river was opened in 1732 with the transportation of approximately 5,200tons of salt being increased to 18,600tons by 1760 (Wallwork 1959). Completion of the Trent and Mersey canal, in 1777, right through the salt field in Cheshire, provided further improvements in transport, and the erection of the Anderton boat lift near Northwich in 1875, to link the canal with the River Weaver, was a result of increased traffic in salt.

The opening of the Trent and Mersey Canal also provided transport opportunities for the alabaster/ gypsum quarries in Derbyshire. The canal was used by quarries at Aston-on-Trent from the late 18th century and a tramway linking them to the wharf was in use from 1812 until the early 20th century (Heath 1977).

The construction of the mainline railway network in the second half of the 19th century not only advanced the movement of salt, but provided a basis for transport of the other evaporites, particularly gypsum and anhydrite, with many mines and quarries having direct links to either branch lines or the mainline itself (Sherlock and Hollingworth 1938, 25-55). The Preesall Mine was connected by rail to a jetty on the River Wyre where the product could be loaded onto vessels of up to 1600 tons displacement (Sherlock 1921, 73; Landless 1979, 38). Within many of the mines and quarries, narrow-gauge tramways, with locomotives, were in use: as at Fauld (Trafford Wynne 1906-7, fig. 7) and at Hawton, near Newark (Howard and Tod 2001). Even when operations still relied on river or coastal shipping, as with the celestine quarries at Abbots Leigh near Bristol (Sherlock et al. 1938, 88), transport to the shipping point relied on tramways.

In the 1930s, aerial ropeways were employed to link a number of mines at Kirby Thore in Cumbria to the processing mill (Tyler 2000, 254), and later, many operations moved to the use of long conveyor belt

Figure 13.2 The Lion Salt Works, Cheshire viewed from the north, July1990 . Bob Skingle, © Historic England

systems for the same purpose. A 5.6km aerial ropeway was used between Brightling Mine and Mountfield works in Sussex (Lake et al. 1987, 92). Pipelines were, and still are, used for long distance movement of brine and one is planned for the transport of polyhalite in suspension, at the proposed York Potash operation in East Yorkshire. At Walney Island the brine was pumped to a holding reservoir, from where a pipeline led to the salt pans (Cubbon 2013).

From the Roman period onwards, settlements in the salt fields of Worcestershire and the Cheshire basin developed around the brine springs. In the latter case, as production expanded those settlements grew, and the salt works moved to the outskirts of the towns. As the industry expanded further, particularly with the advent of rock salt mining, some employers provided dedicated housing for their workers. In 1775, the Barons Croft Salt Works at Northwich had provided workers housing, and by the early-19th century there were other similar terraces around Northwich. Brunner Mond, and other companies, provided housing up until the 1920s when the task passed to local authorities. Even then the large companies encouraged the building of housing by providing land to local authorities for that purpose and, with the expansion of social housing after the Second World War, council houses were specifically allocated to workers in the salt industry (Squire nd). At Walney Island a substantial settlement was planned, but only a few cottages were built and these still survive (Brian Cubborn *pers comm;*)

Outside the salt industry there is little evidence of dedicated housing, although some operations, particularly gypsum/anhydrite mining in rural areas, would probably have justified at least a small number of dedicated workers' cottages.

13.7 Archaeology

Archaeological investigation of salt and the other evaporites has focussed almost exclusively on the processing of the product once extracted, and this is dominated by work on salt works, largely the earlier Roman to medieval sites (Fielding & Fielding 2006). It has to be noted, however, that investigation of rock salt mining in Cheshire is severely hampered by the subsidence and flooding that attended abandonment of the mines. For example, the Adelaide Mine opposite the Lion Salt Works, and the last to work in the Northwich area, is now represented by an extensive area of water infilling the surface subsidence area. The archaeology of the Lion Salt Works itself has, however, been covered recently by Hewitson (2015). The emphasis has been on the history and archaeology of brine processing, be it from brine springs, brine pumping or as the result of rock salt extraction. Such a site at Upwich in Worcestershire, a multi-period site from Roman through to medieval, was investigated in detail in the late 1990s (Hurst 1997). Similar work has been carried out in Cheshire, where two medieval 'salt houses' were investigated at Nantwich (McNeil nd).

Although no salt mines are listed in the National Record of the Historic Environment (NRHE), there has been extensive research carried out to identify the location of all known workings in Cheshire. The 'survey of abandoned salt mine workings and brine shafts in Cheshire' (Wharmby 1987) was driven by the need to identify all abandoned workings with a view to mitigating the associated subsidence risks. Since that date there has been extensive remedial work, particularly in urban areas, and access to abandoned underground working for archaeological purposes is highly unlikely. The survey does, however, provide a useful gazetteer of sites should the opportunity for surface investigation arise. Whittaker (1970) noted the existence of remnants of the Puriton salt works in Somerset, and Landless (1979) provided a plan of the Preesall salt mine site, and noted 'widespread and obvious' surface remains.

Archaeological interest in alabaster arises primarily from its use in ecclesiastical sculpture from the 14th century onwards. The product and its distribution have been researched at length by a number of scholars, most recently by Cheetham (1984, 2001 & 2003). Attempts have been made to link sculptures to particular geological sources of alabaster, but with only limited success (Cheetham 1984, 13, citing Beasley 1978). Finds of tools and other evidence for the early extraction of alabaster, from quarries in the Chellaston area of Derbyshire and at Tutbury in Staffordshire, have attracted comment from time to time (Cheetham 1984, 12) but with little, if any, archaeological follow up. Similarly, stabilisation work on abandoned gypsum mine workings in advance of the construction of the Derby southern by-pass does not appear to have been accompanied by any archaeological investigation (Cooper & Saunders 2002). A number of gypsum mines in Cumbria, East Sussex and the East Midlands were listed in the Monument Protection Programme (MPP) Step 3 report for Lime and Plaster. At least one site, Brickyard Plantation, Aston upon Trent, has been the subject of archaeological assessment (Elliott et al. 1995) and the Acorn Bank Gypsum Works at Temple Sowerby in Cumbria has been surveyed and is listed in the National Trust HER (National Trust ENA1387), but it is not clear if that survey included the extraction site itself (Maxwell 1997). There are currently eight gypsum mines listed in the National Record of the Historic Environment (NRHE). The extraction of potash and salt were included in the Historic Seascape Characterisation for parts of Co. Durham, Teesside and East Yorkshire (Baker et al. 2007, 83-85).

Figure 13.3 Lion Salt Works, Ollershaw Lane, Marston, Northwich, Cheshire. Undergoing restoration 2011. Peter Williams,© Historic England

Tyler (2000) provides a comprehensive social history of gypsum and anhydrite mining in Cumbria, albeit unreferenced, and includes some sketch plans for sites which can be interpreted in the future. Otherwise there has not been much interest in recording and interpreting the remains of the industries in Cumbria. Further south, in the East Midlands, there has been interest over a long period. Evidence for gypsum working in Derbyshire was examined by Sarjeant in the 1960s (1962 and 1963), and Firman (1984; 1989a and 1989b) has documented and attempted to interpret a number of alabaster working sites in the East Midlands from a geological perspective. The work of the latter provides an insight into the archaeological potential for the quarrying of alabaster and, along with Barnes, the mining of gypsum in Nottinghamshire (Barnes & Firman 1991). The Fauld Mine in Staffordshire has also attracted interest, if only for the fact that it was partially destroyed in the largest explosion on British soil whilst being used as storage for high explosives during the Second World War (Waltham 2001; McCamley 2004, 77-139). The surviving features of the Hawton Gypsum Mill, near Newark in Nottinghamshire, were surveyed for Nottinghamshire County Council archaeology service by Structural Perspectives Ltd in 2000 and provided the basis for a detailed assessment of the grinding processes used on that site (Fitzgerald 2011).

Overall, there has been little archaeological investigation of the extractive processes for salt and the other evaporites.

Acknowledgements

Chris Carlon, Brian Cubbon, Mike Gill, David Kitching, David Pybus, Neil Rowley, Geoffrey Warrington, Dave Williams.

Primary Sources

National Archives (TNA: PRO), Board of Trade papers:
BT 356/10262 - Upgang, Whitby, Yorkshire; laying of pipelines by ICI
BT 356/10263 - Upgang, Whitby, Yorkshire; laying of pipelines by ICI
National Trust ENA1387 - Survey of Gypsum Works, Acorn bank

Notes

1. Coastal salt production is outside the remit of this assessment. For further details on the archaeology of coastal salt-making see the work of David Cranstone, particularly Cranstone 2012.
2. The Walney Island deposits were worked by the Barrow Salt Company, the history of which is explored in detail by Cubbon (2015).

14 Underground Archaeology

Lynn Willies

Additional material contributed by John Barnatt and Peter Claughton

14.1 Introduction

Some aspects that relate to this topic have been considered in the separate assessments of mined or quarried materials. In this section, emphasis is placed on archaeological remains found in underground workings. To avoid confusion, unless otherwise specifically stated, mining here refers to the underground extraction of metals and minerals; also stone other than dimension stone. The latter, by historic convention, even if worked underground, is normally referred to as quarrying. This is slightly at variance with 20th and 21st century usage which legally now refers to all underground workings as 'mines', though the term quarry is still commonly used in the remaining dimension-stone industry (*see also* Section 3.1.2).

14.1.1 Types of material worked underground

The choice whether to work at surface or underground has largely been an economic one, mainly relating to the costs of removing overburden, as against the greater ease and lower cost of surface working. However, personal idiosyncrasies of those undertaking the work, and consideration of the various impacts of surface mining on landscape and on (usually) domestic housing, may create pressures to take the industry underground even though direct costs of this were, or are, higher. As a result, the broad classes of most stone and mineral products worked at surface have some instance of underground working. The main exceptions are some of the igneous rocks, where large reserves of good quality occur at surface, sand and gravels, and minerals such as alum, coprolites and celestite.

14.1.2 The location of underground working for stone and minerals

Underground working for stone and minerals has taken place in almost all, if not all, English counties, though certain areas were notable for specific materials. Cornwall and Devon have been especially known for tin (*see* Section 8) and copper (*see* Section 9), with substantial amounts of arsenic (*see* Section 12.1), iron (*see* Section 5) and lead with silver (*see* Section 7) also being raised from within and around areas of granite, and lesser amounts of wolframite (*see* Section 12.3), zinc (*see* Section 7) ores, manganese (*see* Section 12.2), baryte and fluorspar.

Gold has been purposefully worked in Devon (*see* Section 10), and at least one attempt has been made in Derbyshire. Although a very minor occurrence, it has been recovered from chance discoveries in Cornwall and Cumbria, and possibly elsewhere.

Mineral assemblages, largely associated with the Lower and Mid Carboniferous rocks of the Mendips, Peak District, parts of Shropshire, the Mid and North Pennines of Yorkshire and parts of Lancashire include, especially, lead-zinc and some silver, with calcite, baryte and fluorspar, with a few occasional workings

Figure 14.1 Drystone arching of 1861-62 in the Main Level at East Ecton Mine, Staffordshire. © Paul Deakin

for less common metals in these circumstances. These include the small but rich copper deposit of Ecton in Staffordshire and that of Middleton Tyas in North Yorkshire, and manganese ores, 'wad', in the Peak District. Occasional similar deposits are associated with Upper Carboniferous Coal Measures and Permo-Trias as so-called leakage anomalies but whether worked underground is uncertain. Copper (and some cobalt) was mined in Triassic rocks notably at Alderley Edge. The Forest of Dean, and parts of Cumbria (including former Westmorland and the Furness District of Lancashire) worked high grade limonitic and haematitic iron ores. Cumbria was also worked for copper, especially around Coniston and Keswick, and the very unusual economic deposits of plumbago or graphite in Borrowdale and wolframite at Carrock Fell.

The Upper Carboniferous Coal Measures (and the beds immediately below them) were the main source of coal, with coalfields in many parts of England (see Section 4). Coal Measures, often, but not always in conjunction with coal mining, provided large amounts of clay (see Section 6) for pottery, fireclay and gannister (an orthoquartzitic sandstone) for refractories. Some pyrite or 'brazil' has also been produced, some possibly for striking in tinderboxes or firearms, but more probably for manufacturing ink. Some sandstones, such as the Elland Flags in Yorkshire, were worked for slabs and roofing stone. Occasional oil or pitch deposits within the Coal Measures have been worked infrequently by mining, including at Riddings in Derbyshire and the 'Tar Tunnel' at Ironbridge, Shropshire.

Underground working of dimension stone has also been fairly widespread (*see* Section 3). Underground quarrying of metamorphic slate occurred in Cornwall, Cumbria, and in Devon at Buckfastleigh. Slate and some volcanic and durable rock, found whilst mining other materials, were frequently used as by-product aggregates for building and for making local tracks and roads. Dorset has the southwest end of the Jurassic rocks outcrop with notable underground quarries for limestones around Portland and Cretaceous Beer stone in neighbouring Devon. Jurassic stone was also worked in Somerset around Bath, and in Wiltshire the so-called 'Bathstone' was quarried underground in enormous quantities, with similar stone also worked near Cheltenham in Gloucestershire. The Jurassic belt continues up to the North Yorkshire coast, and from Northamptonshire, through Leicestershire the iron content was sufficient for underground mining, though this activity was limited mainly to the Frodingham Ironstones in Lincolnshire around Scunthorpe, and to those of the North Yorkshire Moors. In Derbyshire, specialised stones such as Ashford Black Marble, and perhaps a red marble, have been worked for ornamental purposes. Attempts were made to quarry underground in Derbyshire for Hopton Stone near Wirksworth. However, the large Middleton and Hopton Mines near Wirksworth were, basically, broken and crushed chemical limestone producers. Much the same was true of the limestone mines of Shropshire, and those near Dudley in the West Midlands) (Powell 1999), supplying ironworks in both places with flux. Chert of Lower Carboniferous age has been worked underground around Bakewell, both for edge stones and for fine aggregate (Bowering & Flindall 1988).

In eastern and south-eastern England, chalk has been worked underground both for itself and for the flint it contains; the flint at Grimes Graves in Norfolk was mined in antiquity, with other substantial workings found beneath Norwich. Various sandstones, such as

Figure 14.2 Horse haulage level in Brownley Hill Lead Mine, Nenthead, Cumbria. Probably driven before 1800. Walls coated with stalactites and secondary minerals of manganese and zinc. © James Heaton

greenstone have been worked as sharpening stone, hearth stone and building stone, fairly widely south east of London, finding a ready market in the capital. In Devonshire Cretaceous whetstone mines were worked in the Blackdown Hills. At Nottingham, Permo-Triassic sandstone was worked for building purposes, and perhaps also for the cavities left behind as cellars, whilst substantial underground workings for sandstone have been found under Pontefract in West Yorkshire. Minor outputs have included Carboniferous Elland Flags which have been worked underground for slabs and roofing stone in Yorkshire, and mudstones of a particular grade for pottery manufacture around Chesterfield in Derbyshire.

Industrial minerals still worked underground, include salt (*see* Section 13) in Cheshire and salt and potash in North Yorkshire. Gypsum (including alabaster) is, and was, fairly widely worked including underground in the Trent Valley and in Sussex, with gypsum and, formerly, anhydrite in Cumbria (*see* Section 13). Until recently, this category included the Tertiary ball-clays around Bovey Tracey in Devon (*see* Section 6), where underground mines have now been replaced by opencast working.

14.2 Geology

Detailed geology is considered in other sections (*see also* Section 1). Here, discussion is confined to the broad modes of occurrence of the different classes of material which affect the types of working and the archaeological resource that can be described or anticipated.

This can, very briefly, be broken down as follows:

Igneous: These have been formed by the cooling of magma; if formed deep underground the grain is very coarse, or as finer grained lava if at the surface. Both can yield economic minerals by differentiation of the melt as it cools, forming either a mass type of deposit or, a more or less, narrow zone of finely grained rock close, for instance, to a cooling margin. These modes of formation of minerals have not (on any substantial scale) been exploited underground in England, and igneous rocks are more important as host rocks for vein minerals; their brittleness in orogenic phases leading to fault and joint cavities useful for hosting the vein materials, or sometimes being metasomatised or chemically replaced by the mineral. Granites in the Southwest, the North Pennines and the Lake District may have been important as having high heat flows, providing the motor for mineralising fluids to migrate, whilst layers of volcanic material can act as aquicludes, channelling and ponding mineralising fluids. In some cases the igneous material can be extensively replaced, as at the deposit in the Whin Sill at Burtree Pasture Mine in the North Pennines.

Figure 14.3 Whitewood vein, Rampgill Lead and Zinc mine, Nenthead, Cumbria. Horse level roofed with sandstone dry arching. Floor heave caused by later undermining. Abandoned mine wagon end tipping chassis. Last worked 1922. © James Heaton

Sedimentary: these are laid down in layers, as *beds* or *seams,* as part of the geological succession; though they commonly have, obviously older, weathered, eroded and transported rocks of any kind as their source. These include the Coal Measure rocks, the limestones, mudstones (clays) and sandstones, and beds of salt, potash and gypsum/alabaster type rocks, as well as the ball clays of Devon, which have been derived by chemical breakdown from nearby granite bodies. They are frequently found near-horizontal or gently dipping, but can also be severely tilted, to vertical, as with limestones at Dudley, and some ironstones and coal seams in Staffordshire etc. Sedimentary rocks can also vary considerably in thickness, with clearly a lower uneconomic value when very thin, though thick, incompetent beds can also be very difficult to work. Sedimentary rocks, especially those which are brittle or porous, often provide a host environment for vein minerals, also, rocks such as limestone, are readily replaced by aggressive mineral solutions.

Metamorphic: these are rocks of any type, which have been replaced or altered by high temperatures or pressures, subsequent to their original formation, with new minerals and features such as foliation resulting. Slate is the commonest material of interest, forming large masses from either volcanic (bedded-ashy) material (Westmorland slate), or from mudstones (Welsh slate), though economically useful material may follow the original bedding, due to their specific compositions.

Syn-sedimentary or stratiform: These are minerals which have been emplaced subsequent to the original formation of the sedimentary rock, but their deposits closely follow the original bedding. This can result from chemical replacement of specific horizons (or

horizons under or over an aquiclude), or by infilling of older palaeo-karst cave systems. These are generally called either pipe-veins, or flats, depending on their spatial characteristics, and are common in lead-zinc (Mississipian) depositional environments.

Veins or lodes: Both these terms (lode is more commonly used in Southwest England) have wider usage, but here will be restricted to fissure type deposits formed, normally in faults or joints. These may either be infillings of physically, or solutionally created, space, or be in part, perhaps almost wholly metasomatised replacement deposits. They are commonly highly inclined to vertical, but can, more rarely, be near horizontal, when, for instance, they are commonly given names such as Hading Vein, or Great Flat Lode. Veins can be very narrow, commonly only one metre or so, or wide, up to a hundred metres or more. Sometimes they occur as *swarms*, though these are often compound systems of parallel fissures and microfissures and pipes. Veins also vary a great deal in length. They are affected by a considerable range of 'controls', including the source of the minerals, regional and local dips and features such as folding, soluble, permeable and impermeable strata and by their depth (controlling pressure and temperature) at the time of mineralisation. They may also be affected by secondary events, including near surface or deep-seated erosion and re-deposition (as breccias and placers) and by renewed earth movement and remobilisation.

The more massive igneous, sedimentary and metamorphic deposits are also affected by earth movements and by solutional effects, but they are likely to have far greater persistence and regularity than fissure or pipe-type deposits; nevertheless, high angles and severe folding, or persistent dip to great depths will have a major effect on the economics and techniques required for underground mining or quarrying. Along with demand for the product, the highly variable characteristics, including scale of deposits available within technological phases of development, have a major effect on the date they could be exploited and the means by which that exploitation could take place. As well as the physical remains which have actually already been identified underground, consideration of these characteristics can be used to forecast the likely resource potential of unexplored deposits capable of increasing our knowledge of underground working.

14.3 History of archaeological research underground

The underground resource of England's mines has attracted relatively little attention from trained archaeologists when compared to either surface features of mining and quarrying, or to the study of other archaeological aspects of societies. This is due in part, no doubt, to a relative lack of knowledge of the potential of the resource amongst archaeologists generally and to perceptions about difficulties over physical access, dangers involved in working underground, blocking of access by owners and local authorities, legal impediments and cost. The number of underground sites investigated (and published) professionally in England is very small indeed, perhaps still numbered in single figures. They include Grimes Graves Neolithic flint pits in Norfolk (Longworth 1996); the Bronze Age and Roman copper workings at Alderley Edge, Cheshire (Timberlake & Prag 2005); the Peak District lead mines explored by Barnatt and Worthington (and others); the Ecton Copper mines in Staffordshire (Barnatt 2013); in Yorkshire, by Martin Roe (Roe 2007); at Cheltenham for Jurassic freestone by Arthur Price (2007), and by Willies and others at the Jurassic freestone quarries at Combe Down at Bath, (Willies et al. 2011). There have also been wider studies involving the underground archaeology, such as for the Combe Martin silver-lead mines and other mining features in the Tamar Valley (Rippon et al. 1996), and for mines in Yorkshire and in Cumbria, but of a much lower intensity than those noted above.

Internationally, the research record is better. It includes British involvement, and there is a substantial reservoir of expertise and published output, including for Wales (Timberlake 1994; 2003; Andrews 1994; Lewis 1994) and Ireland (O'Brien 1994). Underground archaeology has been carried out at Rio Tinto in Spain (Willies 1997; Andrews 1994), San Domingos in Portugal, in Germany (in particular), France, Israel, Greece, Romania, Iran, Turkey and India (Willies 1994; Craddock 1994): most of these projects have included a strong British, Belgian, French or German representation. within the teams. The Deutches Bergbau Museum at Bochum in particular, has pioneered the mining archaeology discipline, beginning with the appointment, before 1980, of the late Professor Dr Gerd Weisberger specifically as a mining archaeologist, with publication commonly under the Museum's *Der Anschnitt* label. The Museum has been able to place very substantial resources towards international mining archaeology, with notable results reflected in their publications (e.g. Wagner & Weisgerber 1985; 1988). There is also a high level of expertise amongst French archaeologists with many underground investigations appearing in mainstream publications, for example the work of Marie-Christine Bailly-Maitre at Brandes (Isère) and Saint-Laurent-le-Minier (Gard) (Bailly-Maitre 1995 and 2002). A recent continental development has been the organisation of Institute Europa Subterranea who has published a series of annual symposia on archaeological

Figure 14.4 Engine Vein, Alderley Edge, Cheshire. Worked in the Bronze Age, Roman and post-medieval periods and reworked in the 19th and early 20th centuries. © Nigel Dibben

mining history (Silvertant & Mhairtin 2009).

It is notable that the majority of the above cited work in England is for relatively shallow workings with fairly simple access problems, which has particularly attracted those investigators with a specialised archaeological basis to their education or experience. This was rare in mining heritage involvement, which largely concerned itself with post-1700 mining and quarrying before about 1980, when Andrews, Craddock and Craddock, Timberlake and Willies began their various and often combined investigations, and, after 1990, with Claughton, Barnatt, Worthington and Roe. Before then, the underground mining scene, at least, was dominated by the industrial archaeologist, a term and methodology that has become unfashionable and controversial (*see* Cranstone 2005). Nevertheless a great deal of high quality recording of an archaeological nature was carried out, often in particularly severe conditions under difficult time limits. The adoption of modern, best practice methodologies should improve the quality of this type of underground investigation, but more difficult conditions, especially where time is a problem, can always be expected to compromise the results, whatever the levels of skill and intentions. This type of work was a major feature in mining society journals and in the journal *Industrial Archaeology Review* and, to a lesser extent, some county-based journals.

This is not to say that the domestic corpus of archaeological data for underground working is small. Mining geologists and engineers, especially over two or three centuries, have left a wide range of observations, which describe the technology, features and artefacts, and the human interaction they observed underground, for which there is otherwise little or no published historical data. This is still very much a 'grey source', hidden in a myriad of reports with photographs and diagrams, in mining newspapers and magazines and, probably to a lesser extent, in public archives and libraries. A particularly useful source, especially for coal mines, is the Inspector of Mines' reports following accidents. This is, perhaps, the only non-archaeological form of report that spells out and illustrates the underground situation as found, rather than as regulations or text books, for example, would wish it to be (*see* Sawyer 1886). Fortunately, many technically skilled observers also seem to have been fascinated by early technology.

The 20th century, particularly its second half, saw a rapid rise in interest in caves and old mines, initially as a sporting interest, notably beginning with Puttrel and colleagues in Derbyshire, but increasingly, with the involvement of mainly historically-based societies, a direct, if not always specialised interest in the archaeology of underground mines. This manifested itself in surveys of workings that have their origins as a navigational aid to future exploration, but which progressively began to specifically include archaeological data, much of which could not be acquired in any other way. Many examples of this are available in the journals of mining history

Figure 14.5 Whitesyke Lead Mine, Garrigill, Cumbria. Drinking trough for horses. Mine last worked before 1886.
© James Heaton

societies, but a good deal of potential useful material remains unpublished.

Underground photography, perhaps beginning in a practised way by Burrows with his Cornish and coal mining photographic collections (Burrows & Thomas 1893), has become an important adjunct to this. The photographic collections of Paul Deakin and John Cornwall (both sadly no longer with us), which have appeared in many modern articles on underground mining, form a highly important archaeological record, including for mines now totally, and probably permanently, closed where there is no outlook for future underground investigation.

The advent of new technology, such as laser scanning, has provided further possibilities for a permanent record of underground sections of mines. At Grimes Graves flint mines in Norfolk, an extensive programme of underground laser scanning resulted in a detailed high-resolution 3D image, which has enabled virtual tours of parts of underground sections where the public is not usually able to visit for safety reasons. Similar use has been made of laser scanning at Combe Down using both tripod mounted and borehole systems: an example can be seen on a computer disk enclosed with Lord (2011). Currently, this is a highly specialised and very expensive technique, and is unlikely to be used routinely in subterranean sites that are considered anything other than 'highly important' by funding bodies, though opportunities should be sought where it is already in use, for example, for engineering purposes and costs can be shared.

14.4 Field Archaeology

By their nature, underground workings have a limited surface expression other than their surviving spoil heaps and shaft-head installations. However, often these have been thoroughly effaced. Where it exists, surface infrastructure has sometimes been the subject of detailed study, but lacks the link to the underground elements, which for a variety of reasons remain unstudied. Typically, the entries or openings comprise vertical, or near vertical, shafts; horizontal or declined adits; inclined or level entries for foot, rail, or trackless powered access. Although contemporary workings and abandonment plans exist for many later-period workings, very large numbers and areas of underground workings have no such record, or often, no record at all. Where written or map records exist, much may be deduced about subterranean aspects of mines. This is useful if underground access is out of the question, but such data is also helpful in a programme of underground investigation where access is available. Very often, even the original entries are no longer visually detectable, even by specialists. However, abandoned workings may sometimes be deduced by relationship with other surface mining or quarrying features, and by collapses and subsidence; alternatively they may be rediscovered during earth moving operations, such as opencast coal working or building. They may also be discovered, intentionally or unintentionally, by exploration or site drilling, or by geophysical methods.

The most likely field archaeological remains to be found at the surface is the entry, in the form of a shaft or tunnel. In small mines the entry may also be the working. Entries are characterised by the sectional form, size or lining, and the floor and/or roof and sides and possibly the floor fill. There may be equipment still visible in more recent mines. Any of these features or artefacts may be useful for identification of the date of the operation, the technology in use, and the material worked. In small and favourable circumstances, the entry area may be recorded as an extension of surface recording, using routine archaeological techniques. Examples of this will exist in England, but have been more frequently applied in Wales by Timberlake and the Early Mines Research Group, and in Ireland by O'Brien on Bronze Age mines. In larger instances, and where the conditions for health and safety are more complex, then more specialised skills will be required to assist the archaeologist.

Beyond the entry zone, the range of archaeological features increases and includes the methods of working, drainage and pumping, ventilation, conveyancing systems, the roof support or control methods, lighting, signalling and the disposal of waste rock or spoil underground. There may be features resulting from underground smithing, stabling for horses, emergency accommodation and provision, administration (offices) and, in some cases eating, lavatory and changing (if only

the footwear) accommodation. In a substantial mine or quarry all these may be relatively easily accessible and the associated features in recognisable if not good condition. For example, newspapers retrieved from informal latrines recently, have been useful for providing a date for at least one period of activity within the mine where found with a degree of precision (Barnatt *pers comm*), whilst coprolites are a not uncommon feature in ancient mines in suitable preservation environments.

Both entries and workings may have evidence of secondary use, sometimes as underground factories (Watts Shot Tower, Bristol), munitions storage (underground quarries around Box and Corsham in Wiltshire), mushroom growing, air raid shelters (Byfield Mine at Combe Down, Bath; Pleasley Colliery, Derbyshire), water supplies (Mawston Mine, Youlgreave, Derbyshire), dumps for blown or tipped waste material (High Tor 'Paintmill Adit, Derbyshire), or sometimes for permanent occupation or temporary shelter (crushed sandstone mines or 'caves', Nottingham).

There is an abundance of general description of such features, but investigations to a good archaeological standard are limited, and despite the few examples noted above, this is still largely an under-researched field for archaeological investigation though possessing huge potential.

14.4.1 Underground Technology

Despite considerable published research, a comprehensive overview of mining and quarrying technology and terminology, over the whole archaeological and historical time spectrum, has yet to be published. Generally, accounts have only a limited chronological scope, have a regional bias and terminology, or ignore recent research. The development of such a basic tool for researchers is a major future research requirement. The following is thus a summary subject to these limitations, though it incorporates work done for English Heritage in the various Monuments Protection Programme Reports related to mining produced by Cranstone Associates and Lancaster Archaeology.

The underground technology in any mine, reflected by surviving surface evidence, is likely to have developed over time, but it is necessary to consider that older mines and underground quarries may have newer phases of technology used within, often at deeper or laterally more distant areas of the workings (for consideration how this can be interpreted in some long-life mines, *see* Barnatt & Worthington et al. 2009). Similarly, there will be mines whose remains reflect continuity below ground, perhaps due to access restrictions (e.g. size of shaft), or to a traditionalist outlook of workers

Figure 14.6 Underground horse whim, Scaleburn Lead Mine, Nenthead, Cumbria. The long shaft is the vertical axle of the machine, with a horizontal rope drum. Timbers holding the top bearing have rotted and the machine has fallen on one side. Constructed before 1840. © Colin Fowler

or owners, or dictated by the economics of both an individual mine and the global context within which it was worked. Scale may also play a part: the dominant use of a pick, for instance, probably persisting longer in time in small rather than large mines. Many workings have characteristics of the region in which they occur, or of the miners' origin; for example, Roman, German, Cornish and Derbyshire, all of whom carried specific forms of technology with them. This simple model may be much complicated by reworking, for lower grade, or previously unwanted, 'gangue' material. This can remove much of the evidence of earlier working, though sometimes it can reveal workings that otherwise would have been inaccessible, so that modern reworking can provide fine opportunities for archaeological examination.

Earlier mines, and some underground quarries, including some from quite recent industrially developed societies such as England, often used a 'coyote' type of working, whereby the work followed, or chased, the richer or specifically-desired material. In early mines this was achieved using simple tools such as stone hammers, antler picks and gads (Anon 1998b), possibly bronze picks, and certainly fire, with makeshift 'shovels' of bone and, probably, wood. Wood, reed, leather or other forms of hand carried basket, 'wisket' or 'billy' were used for moving material about. Later examples of what was little more than coyote working, even included mid 20th century fluorspar working at High Loft Mine near Matlock, which used similar but metal tools, and simple systems for conveyance such as wheelbarrows and barrow-ways. However, the simple methods were, sometimes but not always, sophisticated by use of pneumatic drills and explosives. The form and

Figure 14.7 Gullyback Crosscut, Smallcleugh Lead Mine, Nenthead, Cumbria. Impressions of nailed boots, clog irons and horseshoes in clay. Chaired 'T' section wrought iron rail. Dated before1890. © James Heaton

extent of the working may have been, and often was, dictated by the geological characteristics; for example, the fault which determined the limits of the evidence of ancient workings, probably in the form of pits, now left on the wall of Engine Vein at Alderley Edge (Gale 1980; Timberlake & Prag 2005). The extremes of these forms of workings are better exemplified by the simple openings found for Bronze Age copper by O'Brien at Mount Gabriel in Ireland (1994), and by the extensive ramifications of the Bronze Age copper deposit at the Great Orme, Wales (Lewis 1994): English examples generally appear to fall between these, but investigation is still at a very early stage.

In massive deposits such as stone, where followed underground, then the working could become a large sometimes formless opening, the surfaces of which, in bedded stones, reflected the joints and beds used for extraction of blocks. Examples following open joints occur on the southern outcrop of the Combe Down Stone, at Bath (Willies et al. 2011). Alternatively, if a broken 'aggregate' was required, then openings with a rounded, often picked (later blasted) profile resulted, for instance, in the Nottingham sand 'caves' (Waltham 1994).

A shaft and inclined or horizontal entry portal, where sunk or driven through material with no economic value, implies both knowledge of the limits or potential limits of a deposit and a willingness to expend capital to gain access to it. The simplest forms are the bell-pit type shafts, in which the capital was often in the form of a few days labour. However, there is often confusion over the term 'bell pit' because there is no certainty about the form of the underground component if the surface evidence comprises depressions or closely spaced run-in shafts with spoil collars only. Such features at outcrop are possibly better described simply as pits or even pingen (to use a German term) until the underground aspect has been determined. (The controversial term 'bell pit' is further considered in Section 4). Clear examples of the surface expression of bell pits are seen at Grimes Graves, used to access the 15m deep horizon of flint within chalk there, but these, as must often have happened in the transition to other methods, also had flint worked from underground galleries leading off the base of the shafts. Similar pits, called mine pits in the Weald (Straker 1969, 105), or bell pits in Derbyshire and other places, were a particularly suitable method for working repeated layered nodules of ore over thickness of several metres – notably nodular ironstones (Willies 1997a). They were also used for coal mining, usually on a small or domestic scale but many so-called coal mining bell pits (and some ironstone – as at Tankersley in Yorkshire - *see* Crossley 1990, 204) are more simply explained as fairly regularly set-out shafts of shallow depth over comparatively narrow seams worked laterally. They may, however, have been used for mining thick seams liable to catch fire, such as the thick coal near Birmingham, in order to isolate such occurrences easily. Pitting in the form of bell pits, or closely spaced shaft mines, was also used for prospection and along shallow linear deposits, though again many instances are over laterally-persistent underground workings and not true bell-pitting.

Shafts often offered the simplest means of transporting material to surface from underground workings which were low, and especially if the floor was uneven, in seam or pipe workings for example. The number and spacing of shafts was sometimes determined by local customary law, as in areas of the Forest of Dean and Derbyshire, and parts of Yorkshire, but more fundamentally were a function of the depth of the deposit. In shallow deposits shafts were frequent, partly because horizontal underground movement in small workings was so difficult. The deeper the deposit, then the fewer shafts were economically desirable. Often, after the sinking of one or two initial shafts, others were sunk at, or just beyond, the furthest extent of the working, to assist ventilation, access for miners or quarrymen and winding of product to surface.

The effect is particularly evident on coal workings, where distributions range from a few yards apart to several miles. On some metal mines, when progressively sunk deeper, the shallow shafts are often numerous, and the the deep shafts are few; planned or regular systems of levels with sumps or winzes (and staple shafts in some coal mines) were installed from the underground working for both movement and ventilation requirements. At underground stone quarries, the usual massive and strong nature of the material, and consequent large spaces, made it feasible

to develop both long transport and ventilation routes with greater ease, so fewer shafts were required. However, ownership and boundary considerations may make more shafts than necessary technically desirable. Both are observable at Combe Down, Bath.

The size of shafts also reflects stages of technological development; earlier shafts are usually smaller, while the later examples are larger and deeper. Typical early shafts are some 0.7 m diameter; round, oval or square sections may reflect geology such as a fissure, or local custom, and they will often have marks indicating the method of sinking, or be wholly, or partially, timber, stone, brick, iron, steel or concrete-lined. The depth may reflect the 'winding' system used, including carrying up a ladder of conventional or chicken-ladder type, or on holes in the side or on beams across the shaft known as stemples: these can be relatively deep. A cast iron, circular staircase was used at Step Shaft at Wrens Nest, Dudley (Powell 1999). Rope or chain-wound shafts were often constrained in depth by the strength of the material used. Limitations of rope lengths sometimes needed winding to be in stages, requiring hand-operated windlasses ('jackrolls' or 'stoces' or 'stows' in Derbyshire) placed underground. Often there are indications or remains of a plat cut into the rock to house these installations and their operators, or sockets for timbers (observed, for instance at Stadford Mine, near Ashford-in-the-water, Derbyshire). Animal, and later steam- or water-powered winding systems, generally used deeper and larger section shafts: sections of around 1 by 1.5m were not uncommon with horse gin (whim) winding, but in the late 18th century onwards tended increasingly to be substantially larger for use with steam and water power. By the mid 19th century shafts were larger, sometimes 5m diameter or bigger, with greatest depths approaching 1000m (546 fathoms) in Cornwall, for instance at Taylors Shaft, United Mines, Gwennap. Even wider and deeper shafts were sunk in the 20th century.

Associated with shafts will be the impedimenta used for vertical transport, rope (hemp), iron or steel wire, or chains, sometimes leaving grooves and wear marks in the rocks to indicate their existence, with guides, plats, buckets, kibbles, ('corfes') of wood, iron or leather, cages (or remains of them), and pulleys, hooks (clieves) and so on. Ladders, timber brattices and even fully surviving remains of pumping equipment are fairly common in late period shafts (Buckley & Howard 1995; Deakin 1997). The bottom of shafts commonly have graffiti, and personal items such as boots are sometimes found. All materials passed through the shafts (or levels) so almost anything used may be deposited there, including material subsequently dumped from above.

The use of levels (actually normally inclined very slightly to assist drainage and movement of wagons etc.) and declined ways into a mine, depended on needs, availability of capital, policy of the owners and the geological circumstances. Though simple and logical, such entries did not usually become the norm on any but small mines, except for drainage purposes, when they were commonly known as adits or soughs, or drains (differing terms being favoured in different mining districts). This was partly because shafts required less capital. Fairly long drainage adits generally date from around the 17th century, though earlier examples are known, as in Limousin (France) during the late Iron Age (Cauuet 1995) and in Roman Spain (Willies 1997a); they would often have been necessary, perhaps especially so in coal mining. In the Cornubian (Devon and Cornwall) context, drainage adits were described in 1670 (Anon); they were an essential feature of free-draining mines in hilly areas such as Dartmoor until the 20th century, but also served as the drainage level for deeper mines where pumping was required. In the lower-lying flatter district of Camborne in Cornwall for example, many mines were concentrated into a relatively small area and a large adit, known as County Adit, was commenced in 1748 to help drain a number

Figure 14.8 The 14ft (4.2m) diameter underground waterwheel at Brewery Shaft, Nenthead. © Richard Shaw.

Figure 14.9 Harnisha Burn Lead and Fluorspar Mine, Frosterley, Durham. Nineteenth century lead mine horse level reopened as a fluorspar mine around 1970-5. Timber roof supports and steel rails are from the 1970s reopening.
© James Heaton

of them (Buckley 2005, 99). Driving of soughs and adits remained a viable technology into the late 19th century, then and later often used as pumpways. Long adits and soughs, also offered the possibility of cutting previously unknown deposits. Long adits became a frequent feature of the18th- and 19th-century metal mines of mid and North Pennine, because of a thick cover of glacially deposited material at surface. Horses were usually used to move material in long haulage levels, and in the huge stone mines around Corsham, for instance; they left evidence of hoof-prints on the floor (*see also* Nenthead example Fig 14. 7) and rub marks on corners. They were used less frequently after ropeways, or other powered haulage systems were developed, largely, but not exclusively, from the late 19th century onwards.

As with shafts, the methods of driving levels will often be apparent, but in poor ground there will be surviving examples, or evidence of, walls and roofs reinforced with wood, metal, stone, brick or concrete. In some cases, drainage levels, such as the Worsley coal mines in Lancashire and the Dudley limestone workings, were canalised; evidence of locks, rub marks and cable haulage, even boats and loading plats may be visible (Powell 1999 and personal observation). Otherwise the floor will usually have evidence of the transport system, in cleared hard floors, rail (sleeper troughs) or barrow-way remains and later mines may have cabling for power or signalling. Vehicles and mine equipment tended to accumulate and be left behind in levels, so almost any item may be found there. Declined entries may be small, just for easy access, such as footrills, but otherwise will have evidence of hand, or powered, systems of haulage, such as rails and pulleys, carts, wagons or tubs and may have steps. Underground quarries sometimes used similar but usually more substantial equipment. Ralph Allen was an initiator of improved systems at Combe Down quarries from *c.*1730, but railed systems of one form or other were initiated in early post medieval times (Lewis 1979). In the 19th century most substantial mines and quarries had some form of railway haulage, lasting until the trackless haulage systems of the later 20th century.

14.4.2 Ventilation and drainage

These were both used on what can be termed strategic and tactical levels. Both relied on the shafts and passages to house the pumps, or other water lifting devices, such as barrels, and to be the primary routes for an air supply. Where possible, drainage relied on gravity, either direct to the outside, or to the pumps at the shaft. Away from the shaft or below adit level, hand pumps or rag and chain pumps, or even simple bailers, were used to free the local working position. In some cases, horse power was applied underground, leaving remains of winding or pumping gins, (Fig 14. 6) whilst water power was used where there was an exit at lower levels from higher level flows (Fig 14.8). Steam and internal combustion engines were sometimes used away from the shaft. The advent of electricity meant that remote pumping sites, or stations, became a usual feature in larger mines.

Ventilation often relied simply on the use of two shafts (or a divided shaft), but in larger mines either a substantial surface steam, or electric-powered fan was needed, or a furnace to heat and propel the air up the shaft. Alternatively an underground brazier in the shaft, or a furnace at the bottom, could be used (*see* Section 4). Fires were used underground for ventilation, and the use of firesetting, to break rock, had a ventilation effect also. Hand powered fans and bellows were used tactically, and later, electricity or compressed air provided power for local supplementary ventilation.

Flows of water and air were part of the design of the workings, with drainage back to shafts or drainage adits and the use of channels or 'grips' at the side or under a false floor. Wood or iron troughs and small bridges, and even small viaducts, were used to prevent leakage back into the workings. Ventilation was controlled by textile curtains, wood brattices or stone packs. Usually the latter had clay or other infilling of the cracks, or later, lime or cement mortar. In many mines and quarries, the air largely found its own route, especially where there were several shafts or other openings at different levels. The need for good ventilation, especially in coal mines but in other types of mines as well, to provide air for breathing and to dilute asphyxiating (nitrogen or carbon dioxide – black damp), poisonous (carbon monoxide – after damp) or explosive (methane or fire damp) gases, required higher air flows than either naturally dispersed

systems, or designed sequential flows through old workings, could provide. The solution was the adoption of parallel flows of air through ventilation districts, which provided shorter distances, and overall wider passage sections to improve the flow. In substantial mines, ventilation and drainage needs are manifest in the arrangement of subterranean and surface evidence. Artefacts can include the various forms of drainage equipment, such as rising mains, pump rods, waterwheels, and engines, (particularly so in recently dewatered mines, or during droughts) and dewatering is very much incorporated in the layout of the workings. Evidence for ventilation might be in the form of fans or bellows (now dilapidated), but these have mostly been removed, though remains of wood or mud-and-stone ducts frequently survive. In mines worked by fire-setting, airways may sometimes be determined by absence of soot or ash deposits (inflows), or their presence (outflows).

14.4.3 Roof support

This will leave obvious remains in open underground workings, from simple packs of stone left as support for the roof, or to store waste rock behind (deads, gob, discard, spoil), steel supports, or timbers (*in situ* or fallen after rotting)(Fig 14.9), arches and, of course, pillars of rock or mineral left unworked. The shaft is often heavily reinforced and long levels (especially those in the mid and North Pennines) may have long sections of stone arches in corbelled, round or herringbone forms. Coal mining, usually in unconsolidated strata, often used very heavy support with extensive use of timber and iron, and later, steel, brick and (imported) stone.

14.4.4 Methods of working

The method of working refers to the layout of the mine at and near the working faces, and reflects the type of equipment available. The tools and techniques for rock-breaking will be considered first, followed by the more general layout of the workings.

Until modern times, the tools used by the miner were usually very simple, and many remained in use for long periods; stone tools for hammering and crushing were dominant before and substantially into metal-using times until iron became more plentiful. The early use of stone tools underground may have left characteristic battered faces on the rock and the discarded tools themselves often survive. Thus, they generally reflect pre-Iron Age working, though use for crushing, and perhaps as a supplement to firesetting, is possible at much later times; caution is needed before using such tools for dating. Frequently, at such early workings, bone, antler (Barnatt & Thomas 1998) or

Figure 14.10 An old crane survives underground at the freestone mines at Corsham in Wilts. © Richard Shaw

wood tools, for prying, levering and wedging, scraping and shovelling were used, sometimes leaving diagnostic marks. Underground remains of pre-Iron Age working, and of the tools and tooling evidence, is still very rare in England, as is any archaeological evidence of Romano British and medieval working.

Firesetting to break rock, using timber, or sometimes coal as a fuel, is likely to have been in use from the Early Bronze Age until the late 17th century or a little later in mines in England (Barnatt & Worthington 2007a; 2007b), but for longer in some Continental mines and until recently, if still not current, in parts of Africa (T Worthington *pers comm*). This technique often leaves characteristic curved faces though subsequent hammering or picking is not unusual. Fortunately, firesetting nearly always leaves datable charcoal deposits in fireholes or in floor debris, and ash and soot often remains in flueways. It was, and is, an extremely effective means of rock breakage. Detailed recording of methods used abroad (Willies 1994) has now been complemented by discoveries of its substantial post-medieval usage in Derbyshire (Barnatt & Worthington 2006a; 2007a; 2007b) and also in West Devon following the methodology developed by Barnatt and Worthington (R Stewart *pers comm)*.

Metal tools from the early Bronze Age onwards (including steel from the mid-19th century) are evident, either as tool marks or sometimes the tools themselves survive. However, in England, use before Romano-British times is yet to be recorded, and actual examples of their use before late medieval times would be a major discovery. The probable ascribing of a Roman date to a square-profile shaft at Alderley Edge is inferred from the presence of the Roman hoard of coins found there and not reliable dating evidence (see Section 9).

Since iron became available (in the 1st Millennium BC), the forms of iron tools have remained broadly

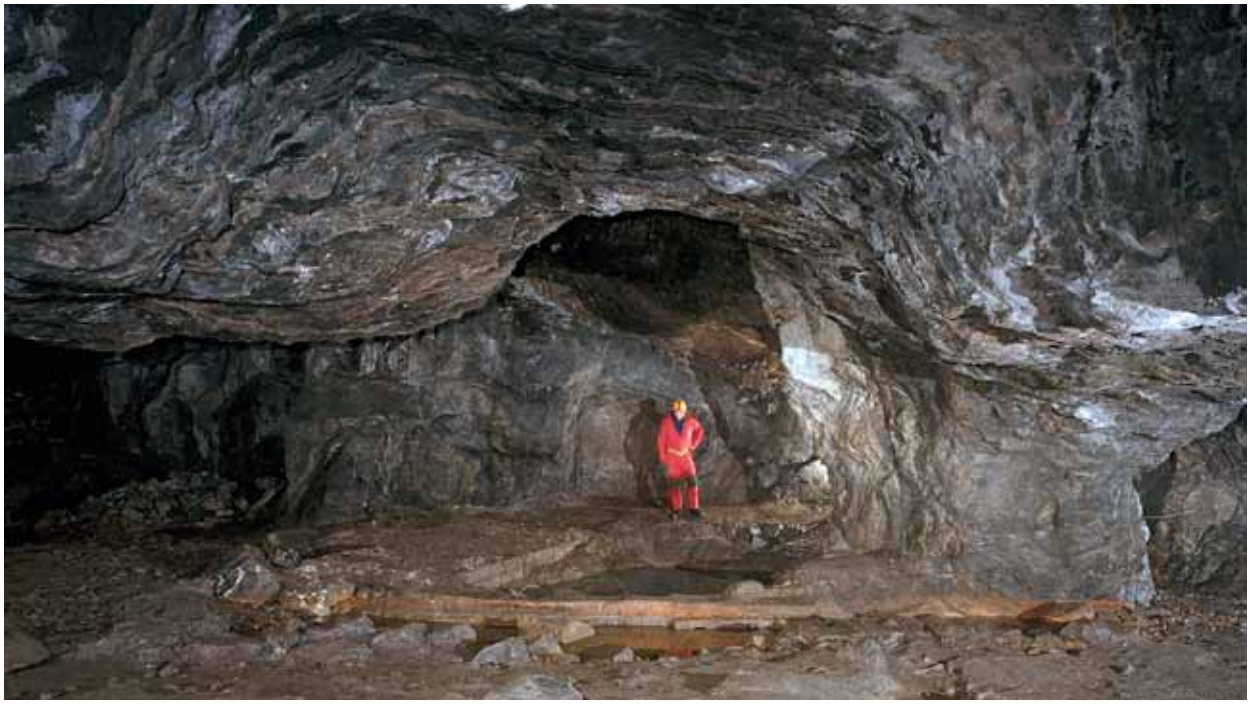

Figure 14.11 The top of the Great Shaft from the capstan chamber at Deep Ecton Mine. The cavity in the roof accomodated the ropes from the capstan/whim or gin to a headframe over the shaft. © Paul Deakin

similar: this is based on evidence from mines outside the UK (Spain for example, *see* Willies 1997a). Most iron tools leave characteristic tooling marks which aid interpretation of breaking methods, but extreme caution is required in using these tool marks for dating purposes (Barnatt & Rieuwerts1998). Local usages may be indicative, but other forms of evidence should normally be used to complement them for dating purposes.

Wedge ended tools, such as hacks, axes, jads (gads), wedges and levers, or various forms of pointed or wedge-ended bars, could be used to work the rock directly, or to loosen or weaken it for hammering. They could also be used to cut slots for wedging by iron or wooden wedges, or by lime constrained by a wooden wedge. Cylindrical holes, which were first developed for plug and feather methods of levering blocks from their mass (largely 17th century in metal mining), became an absolute necessity when black powder or gunpowder came into use (Holister-Short 1994; Barnatt et al. 1997) from the late 17th century onwards. For boring, a borer or 'nogger' – a wedge-ended, metal shaft – was hammered and rotated alternately to produce the cylindrical hole, usually about 30cm deep (Barnatt & Rieuwerts 1998), which is common in workings of the 18th century onwards, and about 18-25mm in diameter. Often there are remnants of the blackpowder and the 'stemming' above it of rammed powdered rock: associated tools included a scraper to keep the hole clean, and a rammer and pricker to make a fuse hole (*see* illustration in Warriner et al.1981). A straw, or goose quill, filled with blackpowder, or after 1840 or thereabouts, a safety fuse, was used to ignite the charge. There are variations which may be significant regionally, and, perhaps, over time, in the case of borer width. Use of nitro-glycerine was often accompanied by mechanical, usually compressed air, borers. Nitro often leaves a characteristic 'shatter star'.

Many smaller ventures did little more than extract visible stone or ore, but larger scale ventures were carefully laid out with transport systems leading to individual working faces (headings or forefields) with facilities to maintain ventilation and roof support. These methods were probably most highly developed in coal mines, where tonnages were high, and where ventilation problems were acute, but all mines have some method lying behind what can be observed. Because of roof falls, the methods in use are not always immediately obvious.

The location from which material was mined or quarried from the solid was termed the 'heading', usually used for the working end of levels, or the 'face' in stratified deposits such as coal, or 'forefield' in metal mines. It took many forms, perhaps particularly dependent on the geological characteristics. In vertical veins, notably those within metal mines, but also some coal and ironstone (Sawyer 1886), the material was usually worked in steps or 'stopes', usually relying on gravity for movement down to a convenient transport location, a shaft or level. Timber ore chutes may survive, where material from the stope has been directed into

skips or tubs running along the level footwall of the stope. In horizontal, or sub-horizontal strata, such as coal seams and some stone mines, material was usually worked by a form of pillar (left intact during working) and stall (where it was removed). The bulk largely depended on the strength of the roof and pillars, but might be extended by temporary support of stone packs or by timbering. Pillars could be removed on retreat and the roof allowed to fall. In other cases some form of longwall were used, with advance across a wide face, using temporary support from stone and timber just behind. Commonly, the roof either settled on the stone packs or collapsed behind except for over roadways, which were maintained to keep them open. In quarries, the more competent stone that was worked, allowed bigger 'rooms' to be left open, but as seen at Combe Down on the usually stepped faces, methods of working evolved to have parallels with the developments taking place in the coal industry.

The methods of working and the faces themselves are not always obvious due to roof-falls and to backfilling. In coal they are sometimes observable in opencast quarries and in repeated sections as the pit develops (Hartley 1994). Many metal mines remain partially and sometimes fully open, though the actual stopes may either be backfilled, collapsed or otherwise inaccessible. Continued access to the footwall of a worked out stope was often maintained by retaining the deads in a higher section of the void with baulks of timber wedged across the opening. These, and stone and steel variants often remain in place. Underground quarries tend to be more open, though surviving visible working faces at Combe Down, for example, are very rare because of backfilling of the 50% or so of spoil. Deeper mines frequently flooded after pumping stopped, but even here dry seasons or limited pumping, even sub-aqua diving (or reopening for mining) can offer opportunities for examination, often with near perfect preservation.

The method of working based on the layout of a mine will evolve over time and usually requires careful survey to determine; but the face, where surviving and accessible, has particular information about the technology, and thus clues to dating. It should have various types of toolmarking, such as hammering, picking, wedging, drilling, use of explosives, and is likely to retain evidence of the method of conveyance used for transporting ore and waste to the surface. Changes in layout in different parts of the workings can sometimes offer valuable information on the sequence and thus possible dates of working.

14.4.5 Artefacts and graffiti

The systematic study of material culture recorded in mines (in conjunction with radio-metric methods) may enable very detailed chronologies to be reconstructed. It can be used to inform us of mining methods and the materials produced, as well as providing information about the miners (and sometimes non-miners), the lives they led and the communities in which they lived. After the mine has been abandoned, later activities in the underground space can be determined. For example, at Combe Down, details of a long-gone village pharmacy were revealed by examining dumped waste. There, it was possible to add substantially to the narrative for the village and help explain its growth, as well as that of the underground quarries, by the use of mining documents and in-quarry waste and graffiti (Willies et al. 2011).

Artefacts found underground fall into several classes: first are the tools and equipment, or their traces, which result from the type of work carried out. These can range from small items, such as candles and lamps (and soot marks) or other lighting, part of workmen›s 'toolkits' (e.g. picks, lamps), to large items such as excavation machinery, engines, pumps, means of support, and their removable or recordable traces. In the case of some mines and some quarries, material can include the product and its processing, such as heaps of stone, stone mouldings or partially processed materials. These are valuable for the information they yield on working methods and products of the mine or quarry. Second are the artefacts left by the workmen including their clothing and footwear, food consumption (bottles, tins, baskets), leisure such as pipes, stone toys or

Figure 14.12 Graffiti incised into the walls of mines: (left) Nestus Pipe above Matlock Bath, Derbyshire. © Paul Deakin; (centre and right) Whitesyke Lead Mine, Garrigill, Cumbria. This mine was last worked before 1886. © James Heaton

Figure 14.13 Early type of compressed air drill bit with wood and iron bucket. Boltsburn Iron and Lead Mine, Rookhope, Weardale, Durham. Mine closed by 1940. © Peter Jackson

figurine making, and the curious clay 'whorls' found in the Old Millclose Mine, Derbyshire (Deakin & Warrener 2000). All such items tell us something about the lives of the people who worked there. Many underground workings have had secondary entries (following the cessation of mining activity), which becomes evident from the artefacts left behind. Often this occurred as the mine took on new uses, including exploration, usually for leisure purposes, and mineral collecting. In easily accessible workings, the dumping of waste was a frequent event. In many places redundant workings and shafts have been used as the local waste management amenity, leaving stratified dumps of considerable value in investigating the history of the local community, undisturbed for a century or longer.

Similarly, graffiti (Fig 14.12) can be divided between that associated working needs and items of a personal nature. In the former category are notices, tally boards and division or way-markers. Personal graffiti might include initials, drawings, insults, contemporary comment and dates. Later visitors may have left their own record, in less desirable forms of graffiti, too often overlying the earlier graffiti contemporary with working, and defacing walls.

Relatively few studies have recorded systematically the artefacts and graffiti found underground in English mines, and too often artefacts have been recovered with their location recorded in insufficient detail. Whether to record or to recover throws up considerable ethical issues which need careful consideration in any underground investigation. In underground working certain to be lost, as the Combe Down Mines (Willies et al. 2011) which were totally infilled with concrete, then items which were portable were generally removed or thoroughly sampled and suitably stored after recording *in situ*. Some items were left as too large or difficult: graffiti judged of high importance on stone faces was recovered either by sawing off the face using a combination of modern tools and the traditional saws, or removed by coating with a synthetic latex which stripped the image from the face, and in turn was stripped from the latex on to a long-life resin sheet. Both techniques were effective, but expensive. In Old Millclose Mine, where access is difficult thus protecting the features found, the decision was made to leave the abundant artefacts untouched, with recording by photography (Warrener et al. 1981). In the Wapping and Cumberland Mines (Barnatt & Webb 2002), visitor trespass by the so-called 'Trogs' in the 1950s onwards has left walls covered with graffiti. It has considerable informational value, albeit usually being considered undesirable.

14.5 Advantages and limitations

The preservation of artefacts and organic material discovered underground, is often much better than material found at surface. In some cases, even when very old workings are examined, the scene is just as left by the miners (Warriner, Willies and Flindall 1981, Deakin and Warriner 2000). In India for example, pre-Maurian mining (prior to about 2300 years ago) had left ladders, dams, pre-formed timbers, fireholes, steps, pots used for carrying water and lamps *in situ* in almost perfect condition; similar finds have been preserved in Spain, Israel and Turkey (Willies – *see* www.pdmhs.com), due to the copper and zinc content of the water. The flooded workings at Ecton, where detailed archaeological survey has been carried out in the upper levels by Barnatt (2013), could, with a relatively modest pumping effort, offer similar opportunities. It follows that any reworking of old mines in this country, as for instance in Cornwall, should be subject to archaeological monitoring, and detailed recording including excavation as necessary.

Because access to many underground workings is easily controlled, archaeological work can be carried out over a substantial time span, without the risk of intruders damaging the site. Many mines are so extensive, or the archaeology in many areas both simple and repetitive, that the potential for useful excavation is limited, so the site can more easily be preserved. Working in conjunction with modern reworking can also offer equipment, access and lighting opportunities at least equal to those available for surface sites.

The difficulties break down into a few main categories: the most obvious is the physical difficulty of access for personnel and equipment and the need for reasonably safe working conditions. This will vary depending on whether the investigation is affected by the full health and safety requirements of the Mines Inspector, which appear to not apply fully where the investigation is

a voluntary unpaid activity in an abandoned mine or quarry. For example, within the projects undertaken by mining history societies or small groups of individuals. As the work at Combe Down has shown, archaeology can be done within a work environment, but the costs can be high for all but basic monitoring. In this example the archaeological activity was carried out in conjunction with the engineering work that was required for the stabilisation of the underground quarries. In some cases, modern opencasting or open-pitting can give temporary (but final) access to underground features, recovering a good proportion of the information which would otherwise be totally lost forever; the recording undertaken by the Leicestershire Museum Service at Coleorton coal opencast quarry (Hartley 1994) is among the best examples of this scenario. The wet and rugged environment underground can also take its toll on equipment, limiting the use of expensive survey kit (laser scanners, total stations etc) to the less harsh sections of a mine.

A further major access limitation is depth, and the flooding which normally takes place within a few hundred feet of surface. In many respects this can provide an excellent preservation environment, perhaps especially in copper mines which prevent decay. Modest amounts of water, down to depths of 50m or so, can be successfully pumped by hand, as several operations by members of the Peak District Mines Historical Society have shown. Sub-aqua diving has yielded archaeological data, and some flooded workings have been surveyed. Greater depths may become feasible from commercial re-opening of old mines and quarries, which has permitted archaeological investigations abroad, but not yet in England.

The second limitation is legal. It is often claimed that coal mines cannot be re-entered legally by members of the public (i.e. it is a criminal trespass), even where fairly simple access is feasible with very modest (though specialised) health and safety needs. Ivor Brown, (*pers comm*) has commented that he is unaware of the legal basis for this claim but the Coal Authority is unlikely to permit access underground in abandoned workings. Similarly, it is a criminal offence to trespass on MoD property, which will include some of the underground quarries near Box and Corsham. In this case, however, permission for recording was given for the Foxhill underground quarry under an active MoD establishment at Combe Down, and a more open attitude seems to prevail with the Wiltshire quarries where English Heritage has already had some involvement. Outside these limitations, access to abandoned mines is allowed by agreement of the landowner, who appears to have protection against claims where suitably experienced people are involved. This may be the case with acknowledged specialist underground exploration societies and teams. Nevertheless, the legal basis for any underground entry to carry out archaeological investigation has to be properly established before any work begins.

The third limitation is cost. In the two cases (Coleorton and Combe Down) cited above, major archaeological recording was carried out in association with the engineering needs of opencasting and stabilisation respectively. The recording costs, though substantial, were minimal in comparison with the huge costs of engineering, and much cost applied to the archaeology would have been incurred anyway. Many important investigations, such as those by Roe, Barnatt and Worthington are either financed to a modest degree by archaeologists, or under a modest grant intended to allow the research to go ahead as part of an academic programme. Between these extremes are a very large number of opportunities, a few of which may be financially possible but which can only be carried out if adequately funded.

The opportunity for major discoveries underground is considerable, but physical and legal access problems pose major problems in some situations. In many others, legal access is possible, but health and safety when at work will probably require such investigation to be done on a voluntary, possibly grant-aided basis, by groups or societies with the requisite skills. Where possible, major earthmoving, or mining and quarrying work, in areas suspected to have older underground workings should be archaeologically monitored with provision for substantial recording in conjunction with working. As at Combe Down, when high grade (equivalent to schedulable quality) features are discovered, they must be recorded before they are destroyed. Written permissions should therefore include high priority provision for archaeological recording, with technical support from the contractor. Often this can be done rapidly using photography, video and laser scanning (including down the drillhole scanning) so this can be built into the programme.

14.6 Underground archaeology: the new frontier

Over the last decade there have been significant advances in the investigation of the underground archaeology of mining and quarrying in England. On the one hand there has been the work by Oxford Archaeology at Combe Down (Willies et al. 2011), which is on a far larger scale than any carried out to date, and is unlikely to be repeated in the foreseeable future. The other important advance is the growing number of investigations by a small group of well established, skilled archaeologists

working mostly in the voluntary sector. Work by Barnatt, and others, exploring and recording mines in the Peak District (Derbyshire and Staffordshire), and investigating issues such as the evidence for firesetting, has set a high standard (e.g. Barnatt 2013; Barnatt & Worthington 2009). There is also an increasing number of mine explorers recognising and embracing the need for archaeological investigation, notably in Southwest England (Lakin et al. 2011; Stewart 2014) and on the Calbeck Fells in the Northwest (Allison 2010).

Underground archaeology in England cannot be considered in isolation to that in other parts of Britain and Western Europe as a whole. As alluded to above, there is a considerable body of expertise and experience, which any study of the underground archaeology in England might draw upon. In Wales the work of archaeologists employed by the Royal Commission on the Ancient and Historical Monuments in Wales, including the surveying of mining features, has been taken underground at Ystrad Einion (Ceredigion) to capture the complex detail of an underground waterwheel (Coflein,Ystrad Einion[1]). In the Netherlands there is expertise in the investigation of underground quarries (see, for example, Silvertant 2009) and in both Germany and France, detailed examination of working techniques using the subterranean evidence are well advanced (Adlung & Strassburger 2009 and Pierre & Wéber 2011, respectively). A basic historiography of pan-European metal mining archaeology is provided by Fluck (2014).

A brief assessment of the current state of underground archaeology as an integral part of the historic mining landscape in Britain, was provided by Claughton (2010b) but it is the report to English Heritage on The Subterranean Industrial Legacy (Barnatt *forthcoming*), which will highlight the quality and value of the underground archaeology in England. Barnatt reviews the nature of the underground heritage assets and addresses the issues of conservation, and the potential for statutory designation. His report emphasises that there will be a reliance on expertise within the voluntary sector if the underground assets are to be realised to the full, not only the expertise in accessing a subterranean environment but also in developing the archaeological skills necessary to assess those assets. Parallels might be drawn with the development of marine archaeology over recent decades, with underground as the new archaeological frontier.

Internet sources

1. http://www.coflein.gov.uk/en/site/415676/details/underground+water+wheel%2c+ystrad+einion+metal+mine/

15 Archaeological Science Techniques

Adam Russell

15.1 Introduction

The use of scientific techniques in archaeological research is by no means new, but over the past 50 years there has been a great increase in the number of analytical techniques available. Thus, there are numerous tools on hand for the archaeological researcher, and in the field of mineral extraction these techniques offer many opportunities for discovery. A good basic introduction to current scientific techniques in the context of industrial archaeological research has been published by English Heritage (Dungworth & Paynter 2006), and although this is primarily aimed at post-medieval industry, the techniques described can and have been used for earlier sites and artefacts.

For the purposes of this section, the available techniques have been broadly grouped into four areas: dating, location and recording, characterisation, environmental. These are not mutually exclusive and there is a great deal of overlap between them.

15.2 Dating techniques

The most commonly-used scientific dating technique employed in archaeology is **radiocarbon,** which requires retrieval of organic material from reliably excavated contexts. The theory and method behind the technique has been widely discussed elsewhere. It is a routine technique for archaeologists and has been used frequently to further research into extractive industries such as the investigation of ironworking in the Blackdown Hills (Griffith & Weddell 1996) and firesetting in the Peak District lead mines (*see* Section 15.2.1, case study) to name just two examples of many.

Two other dating methods based on measuring the decay of radioactive elements, **potassium/argon** dating (K/Ar) and **uranium-series** dating, both of which were developed for geological purposes, also have possible uses in mining archaeology. K/Ar dating is generally useful for potassium-containing minerals formed over 100,000 years ago, while U-series can be used on calcium carbonate. Although not suitable for dating of the actual extraction or processing of material, these techniques have potential for identification of rocks and minerals as part of provenance analysis.

Archaeomagnetic dating can be used on fired clay or stone, to try to establish the date of the last firing. During heating, the magnetism of iron within the fired material aligns itself with the direction of the earth's magnetic field, and careful analysis of the sample can produce a date based on this. This is particularly so for more modern samples, as there are accurate records of magnetic declination in England from 1650 onwards. As the primary processing of extracted materials often involves heat, this offers an alternative dating route for structures such as kilns and smelters, and has been employed successfully to date a limekiln in the Yorkshire Dales (Johnson 2008).

Ceramic artefacts and structures also have the potential to be dated by **thermoluminescence**, as do sediments which contain crystalline materials. This technique can detect the time that has elapsed since either the last heating or exposure to sunlight, by releasing energy built up within crystal structures over time through heating, then measuring this energy, which is emitted as faint light and can be correlated with a timescale by measuring its intensity. Sediments can also potentially be dated by the related technique of **optically stimulated luminescence**, which uses strong light, rather than heat, to release the stored energy. This technique was used successfully on sediments from Exmoor, which related to two phases of mining activity, and showed that the initial mining was carried out during the Roman era, with a second period of working in the 17th century (Brown, et al. 2009).

There are two further dating techniques which do not appear to have been used for researching mineral extraction to date. Firstly, **dendrochronology** (tree ring dating) offers some potential for the dating of larger wooden items, although the reliability of any date so obtained would be dependant on the nature of the artefact and the timber from which it was fashioned. In particular, care would have to be taken with artefacts from post-medieval mines as imported timbers such as

pitch pine were in common use.

Through a combination of radiocarbon and dendrochronological techniques, there is great potential for the dating of wooden artefacts, such as stemples, props, rising mains, barrows and tools, which often survive in the subterranean environment of metal and stone mines.

The second technique is **lichenometry**, which analyses the growth rate of certain species of lichen. This raises the possibility of getting an approximate date for the exposure of a rock surface. At present this is untested, but it may prove useful at ancient quarries or opencasts.

15.2.1 Case Study – radiocarbon dating of mining by firesetting in the Peak District

As part of an ongoing study into the use of firesetting in the Peak District (Barnatt & Worthington 2006, 2009), one strand of the research has been to try and establish a range of dates from sites where firesetting evidence has been recorded. Documentary evidence suggests that firesetting had mostly fallen out of use by the beginning of the 18th century in favour of gunpowder blasting, an assumption which needed testing, but there was also the question of when the technique first came into general use. Historical sources suggested that within the Peak District orefield, the main fuel used for the firing was coal, and examination of fireset areas within mines showed that this was generally the case. However, some wood had been used, either as a primary fuel or as kindling, and a number of apparently undisturbed fireset areas were subject to limited excavation to recover samples of charred wood. Eleven samples were retrieved, selected for processing following species identification, and passed over to the Oxford Radiocarbon Accelerator Unit for dating using AMS, and a further four samples were processed by Beta Analytic of Florida. The results suggested that firesetting began to be widely used in the Peak District around the latter half of the 16th century; it increased in use towards the middle of the 17th century but declined fairly rapidly around the end of that century at about the time that gunpowder was generally adopted for rock breakage.

Figure 15.1 Evidence of firesetting at Old Hen Mine, Hassop, Derbyshire. Potentially dateable charcoal may be found in the debris at the base of the fired area. © Adam Russell

15.3 Characterisation techniques

The most basic scientific technique used for characterisation is **optical microscopy**. At low magnification samples of material can be examined in an unprocessed state. However, for higher levels of magnification it is usual to prepare a polished surface or sample of the material to be analysed with reflected light. This allows the microstructure of the material to be examined. Practical, non-geological examples of this technique include the analysis of wire ropes from Cornwall, in which a discussion on the relative strengths was based on microscopic examination (Morgan 1996), and an examination of a rock-splitting wedge recovered from Dirtlow Rake in Derbyshire, where a combination of microscopy and hardness testing revealed how it had been formed (Murphy 1970).

For analysis of geological materials, the usual practice is to prepare a translucent thin section of material and examine it under the microscope using transmitted light, either unaltered or using polarising filters. As the most likely use of this technique, applicable to extractive industries, is in determining provenance, it will be covered in that section of the assessment (see below). Apart from identification of the source of a mineral, it can also show indications of human activity causing changes within mineral structure. One example not yet tried on an English site, but successfully applied in Finland (Kinnunen 1988, 143-5), is identification of firesetting activity through observing decrepitation of inclusions in gangue mineral crystals. Another example of a mineral affected by heat is feldspar; by examining the deformation of the crystals in samples excavated from the Linch Clough bole site in Derbyshire, it was possible to establish the hearth had reached temperatures of 1200°C (Bevan et al. 2004).

Far higher magnification is possible using an electron microscope, where, rather than using a beam of light on the sample, a beam of electrons is fired at it. The use of an electron beam also allows compositional analysis of a sample if coupled with the various techniques which use the interactions of the electrons with the sample, usually through the stimulation of X-rays by the electrons hitting it (see below).

One of the most widely-used spectrographic techniques is **X-ray fluorescence** (XRF), which provides a bulk analysis of the elemental composition of a sample. Although only the surface of the target material is examined, it is possible to analyse some reasonably large samples. It also allows relatively fast analysis of a number of samples and hence comparison of composition, for example, samples of slags from a number of sites (Gill 1986). There are also portable machines which enable examination to take place *in-situ*. This has been used to carry out analyses of cobalt-bearing rock underground at Alderley Edge (Timberlake & Mills 2003), also as part of recent work at Ecton Hill looking for smelting sites (J Barnatt *pers comm*).

As well as straightforward XRF, the various forms of **X-ray spectrometry** can be used to analyse much smaller areas on a sample in an electron microscope, and thus can determine the composition of individual phases or areas (see Crossley 2006). This is particularly useful for heterogeneous materials such as smelting slags, and these have often been analysed in this manner (McDonnell et al. 1991, McDonnell 1998, Malham et al. 2002, Smith & Murphy 2003, Smith 2008).

X-ray diffraction (XRD) is commonly used for material identification in geology and can be usefully transferred to the study of mines. A beam of X-rays is directed at a small sample of powdered material and a diffraction pattern is collected on film. The pattern of lines so produced is dependent on the crystal lattice and elemental composition of the sample material, and so can be used to identify the minerals present in the sample.

When it is desired to quantify the amount of a specific element in a material, **Atomic Absorption Spectrometry** (AAS) is often used. The absorption of a specific wavelength of light is measured in a sample following calibration against a known sample. The technique has been used to detect heavy metal levels in peat bogs as indicators of smelting activity taking place nearby (Mighall et al. 2004).

A technique widely used for provenancing is **Stable Isotope Analysis**, where the relative amounts of isotopes of a particular element are used as a means of discovering the point of origin. Although there are various elements with which this can be done, the one of greatest potential for use in researching extractive industries is lead, and possibly the metals that occur naturally alongside, including copper. There are four stable isotopes of lead and the relative ratios of them can be examined to potentially pinpoint the source. However, there are a number of problems with this technique: primarily, the likelihood of recycling and intermixing of lead from different origins, and, more pertinently for England, the relative ratios of the lead isotopes in the Mendip and Peak District orefields are too similar to allow them to be distinguished. This problem was noted when some prehistoric lead artefacts from the Peak District were analysed in this manner (Barnatt & Doonan 2010, Pashley & Evans, n.d.), which showed that the source of the lead was either the Mendips or the Peak District, but could not be more specific. An attempt at provenancing the metals contained in silver coins from the ancient world has met with some success across continents – Europe and South America – (Desaulty , et al. 2011), although whether this would work as well comparing separate regions of Europe has not yet been tested.

15.4 Environmental analysis

Any extractive activity has an impact on its environment. This may be minimal, such as the very localised impact of a small quarry, which will only really change the environment of the quarried-out area, or more massive, such as the large swathes of polluted ground that can result from the processing of metal ores. Through analysis of environmental changes in the past, information about contemporaneous human activity can be identified, and extractive activities are no exception.

Direct evidence of mineral extraction and processing can be derived through **geochemical** analysis by identifying traces of the extracted material spread from its original source during its removal, or through processes such as smelting. Such material may be present in the soil at or near the site of extraction, for example, manifesting as enhanced metal levels around the course of a lead-bearing vein which can be mapped through analysing multiple samples (Bayliss et al. 1979). With water-transported sediments, the deposit location may be some significant distance from the original extractive activity but this can still provide useful information both about the type of extraction and potentially the date. An example is the work done by Hudson-Edwards et al. (1999) looking at sediments from the river Ouse; these showed that lead derived from the valleys of the Ouse tributaries was finding its way downstream, and the authors concluded this was due to medieval mining activity, although this interpretation has since been questioned (M Gill *pers comm*). Similarly, evidence of early smelting in Derbyshire

has been found in stream sediments (Kiernan & Crossley 1992). Likewise, within the Exmoor work already referred to (Brown et al. 2009), sediment layers were shown to have derived from mining activity in the vicinity and, through the calculation of the approximate date of burial of these sediments, the mining activity could be dated. On Dartmoor in Devon, evidence for pre-medieval tinworking is elusive, but Roman and post-Roman period tin working have now been confirmed through sediment analysis of natural water courses as they flow through the hinterland (Thorndycraft et al. 2004), although this work was unable to pinpoint the location of any tinworks associated with deposits of those periods.

Processing of the extracted material into a useful form may also release contaminants into the atmosphere, which can help identify both the location of the activity and give some idea of the date. These contaminants may occur in soils and sediments, or through being absorbed by living material such as wood. Peat deposits are particularly suited for such analysis and recent work on Bodmin Moor and Dartmoor has looked at the chronology of tin, copper and lead deposition within upland peat (Meharg et al. 2011). This work demonstrated that the first major prolonged influx of tin pollution was at around 100AD, though it decreased between 400 and 700AD. Surprisingly, lead is detectable earlier from around 300BC but fading by 100AD. A slightly different means of utilising geochemical analysis is plotting the pollution plume downwind from a smelting site, which has been done for bole smelting sites through systematic soil sampling followed by determination of lead levels (Eastwood & Wild 1986).

As well as the presence of contaminants, **pollen records** in sediment sequences may reveal changes caused by industrial activity. For example, pollution may cause the decline of certain species, and the increase of others more tolerant of a contaminant (see below), while the demand for wood to use a fuel can often be detected through a decline in tree pollen.

Fig 15.2 The metallophyte plant Spring Sandwort is commonly known as Leadwort due to its frequent presence on former lead-mining sites. © Adam Russell

Another potential indicator of former industrial activity on a site is **ecological** analysis, looking at the plant communities that have established themselves on a site, particularly where there has been metal contamination. In such cases, the presence of metallophytes, which are species tolerant of high levels of heavy metals, acts as an indicator of the former industrial activity; this has been studied in both the North Pennines and the Peak District (Buchanan 1992; Penny 2009).

15.4.1 Case Study – evidence of mining and smelting activity as derived from North Pennine peat samples

Peat bogs are a major source of material for environmental analysis; they preserve both samples of vegetation and pollen sequences, often over a long period of time, but they also record atmospheric pollution. In an area where there has been extensive extraction and processing of heavy metals, such as the North Pennine valleys, the presence of heavy metals, like lead and zinc, in peat bogs is to be expected, and systematic analysis can provide much useful information about the chronology of metal production in the area.

Mighall, Dumayne-Peaty, and Cranstone (2004) undertook thorough analysis of peat samples taken at three locations in the North Pennines. Block and core samples of peat were taken at a site near the Tees headwater, and at two locations near Rookhope to the north of Weardale, both of which were known to have had extensive mining and smelting activity in the vicinity from medieval times into the 20th century.

In order to establish an absolute chronology, fourteen samples were taken from various points on the peat cores with their positions measured, and samples taken for radiocarbon dating at the same spot. In the meantime, quantification of lead, zinc and iron concentrations in the peat samples was carried out by **atomic absorption spectrometry** (AAS). An analysis of the pollen sequences contained in the peat samples was undertaken.

By comparing the results of these separate analyses and estimating the times of deposition of the analysed points on the peat using the radiocarbon dates, an environmental history of the upper valleys of the North Pennines was established. Although there were times through prehistory and the Roman period, where the amount of tree cover was reduced, there was little lead detected in the peat laid down. Comparison with other sites where Roman lead smelting is known to

have occurred in the vicinity would suggest that lead extraction was not taking place in the area during that period, and this pattern of activity continued up to around 1100AD when the pollution record inferred that limited smelting activity was taking place. From the 14th century onwards, there was a marked decline in tree pollen coupled with a slight increase in lead levels, but lead levels increased significantly at the beginning of the 16th century, continuing to a peak in the mid-19th century and declining in the 20th, which correlates well with the established historical narrative (Mighall et al. 2004, 13-38).

15.5 Remote sensing and landscape analytical techniques

There are a number of techniques well-established in archaeology for remote sensing of buried features without excavation. All of these function by detecting and recording variations in physical properties of the ground beneath, along with their coordinates. A map is then produced showing high and low responses, from which buried features may be inferred. A useful guide to techniques currently used in archaeology is published by English Heritage (English Heritage 2008b).

Magnetometry measures the magnetic susceptibility of the earth directly beneath the instrument, and, like conductivity (see below), the instrument's sensors do not have to be in direct contact with the ground, which allows very rough or rocky ground to be surveyed. As strong heat can have a magnetising effect this makes this technique particularly useful in trying to locate remains of pyrotechnic processes such as smelting or roasting of metal ores. Early lead working sites in the Yorkshire Dales have been studied using this technique (Hamilton et al. 1999), a bole smelting site near Sheffield (Powell 2005; 2008) and the iron smelter at Rievaulx Abbey likewise (Vernon et al. 1998a).

Resistivity is the longest-established geophysical technique, which can identify buried features through the varying electrical resistance of the ground between a number of probes, primarily through variation in soil moisture levels. As with magnetometry, pyrotechnic processes can produce features that give a strong response, with the result that smelting sites have been successfully examined using this technique (Hamilton et al. 1999; Vernon et al. 1998a, b).

It is also possible to use **conductivity,** rather than resistivity, for remote sensing; this has somewhat lower sensitivity than resistance but has one advantage over resistivity in that a conductivity instrument does not need to be in direct contact with the ground.

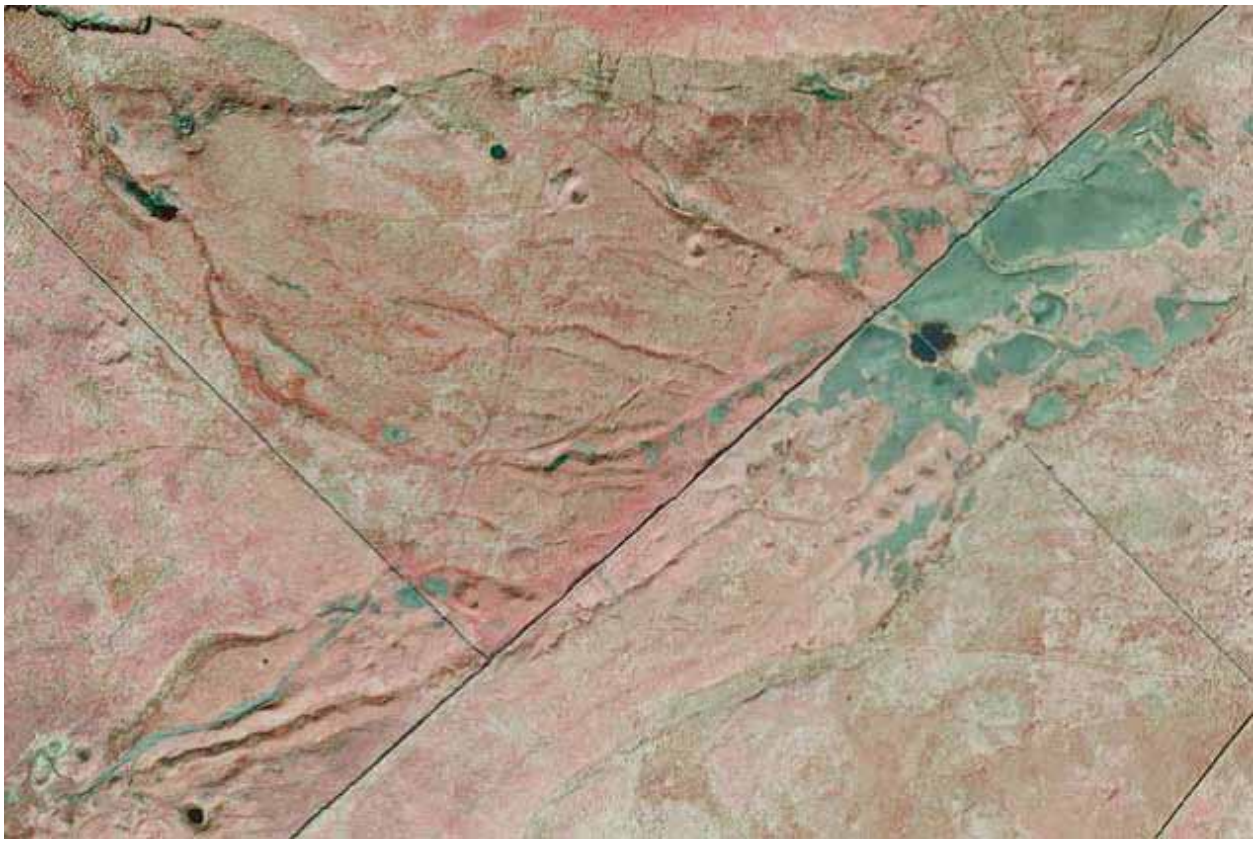

Figure 15.3 Colour infra-red aerial photography highlights areas of lead-mining waste and other features around Fletcheras Mine in the North Pennines AONB. Infoterra Ltd © Historic England

Ground-penetrating radar (GPR) has one great advantage over other geophysical techniques in that the responses from the radar pulses can be correlated on a computer to try and give a three-dimensional image of subsurface features. As with all geophysics, the resolution is highly dependent on the nature of the ground and industrial sites were initially thought to be an unpromising subject, particularly where there were layers of demolition rubble or other waste materials. However, usable results can be, and have been, obtained from the sites of demolished industrial buildings (*see* Hamilton *in* Dungworth & Paynter (eds) 2006), and buried voids at mines have also been detected (Sharpe 1994).

LiDAR (Light Detection and Ranging) has proved to be of worth in recent years for generating three-dimensional images of landscapes, which are useful for reconnaissance, as a precursor to ground investigation, or as a basis for desk-top surveys. It has an advantage over conventional aerial photo plotting from modern images, because tree cover can theoretically be eliminated from the data, revealing the ground beneath. This makes possible a modelled representation of the actual land surface without detail being obscured. However, in practise this is not straightforward and the features revealed in tree-covered areas will always require careful ground checking to establish their authenticity, while results in conifer plantations have very limited usefulness. The technique has been used with some success on mined landscapes in the Forest of Dean, which are otherwise difficult to see because of tree cover (Youles et al. 2008).

LiDAR is more reliable in areas of open country and is currently being used to great effect as part of the archaeological survey of Alston Moor, where much field evidence for the lead industry has now been recorded as a result of its use (Ainsworth 2009; Oakley et al. 2012). As the data are collected from the air, LiDAR has the added advantage of being able to cover far more ground than manual reconnaissance techniques, although this is offset by the fact that the processing of the data is time consuming and very expensive. Being computer-based, the geo-referenced survey data can be integrated and interpreted alongside other data sets through the medium of GIS (see below).

Figure 13. 4 An overlay of part of a scanned 1840s map of the mines on Longstone Edge, Derbyshire onto publicly-available satellite imagery from Google Earth™, allowing identification of vein and shaft locations obscured by modern fluorspar extraction. Images © of the Derbyshire Record Office and Google, overlaid by Adam Russell.

Another survey technique which is showing great promise is the use of aerial photography in the non-visible light spectrum. As part of the ongoing work on Alston Moor, infra-red aerial photography has been used to identify areas of mining activity, where ground contaminated with lead and zinc appears different from the surrounding landscape (Catell 2011).

Global Positioning System technology (GPS) has enabled rapid electronic recording of site locations, and enhanced the capability of detailed analytical survey. Professional survey quality equipment allows a high degree of accuracy and has been used to great effect recording surface evidence of mine and quarry sites at large scale by, for example, the English Heritage AS&I teams in the Lake District (Oswald et al. 2008), Dartmoor (Newman 2007; 2011) and Exmoor (Riley & Wilson-North 2001), while the low cost of navigational quality GPS makes these devices easily available to anyone wishing to undertake fieldwork for recording spatial data and produce basic distribution maps of classes of features. This has been effectively used to survey and record the Greenhow Hill area (Roe 2003a, b).

The use of **laser scanning** also allows three-dimensional recording of sites and artefacts, and can be used to create an accurate record of underground workings (*see* Section 15.5.1, case study). One of the earliest successes with this technique was at Grime's Graves flint mines in Norfolk, where an extensive programme of underground laser scanning resulted in a detailed high-resolution 3D image. This has enabled virtual tours of parts of underground sections where the public is not usually able to visit for safety reasons.

Scanning digital cameras, which build up a composite image from multiple exposures, can be used for panoramic recording of a site and for remote measurement of features. This technique has recently been trialled underground in Derbyshire with promising results (Beck 2011).

The rapid expansion of computing power and usage in recent decades has perhaps been most noticeable in the field of survey and recording. All the above techniques are now dependent on computers for processing and output, and some, such as LiDAR and laser scanning, would be impossible without a great deal

of computing power to handle the vast amount of data generated. The use of **geographical information systems** (GIS) has also revolutionised the presentation of information, as the multi-layering capability of a GIS program allows many separate forms of data to be combined onto a map base and manipulated, which greatly aids understanding of features and cross-referencing of different data sets. For the English Heritage Grassington Moor survey, geo-referenced, ortho-rectified, aerial photography, together with OS map bases supplemented by GPS terrestrial survey, were combined to form a suitable data-set on which a programme of threat amelioration could be based (Ainsworth & Burn 2009). GIS has proved useful both as a research tool, revealing much about data sets that is not immediately obvious through more conventional observation, but has also now formed the basis of most HERs as a cataloguing tool. The easy availability of free satellite imagery, mapping data and low-cost navigational quality GPS also puts this sort of analysis into the hands of any computer-literate researcher, without the need for expensive hardware and software.

15.5.1 Case Study – Laser Scanning at Combe Down Stone Mines

Extensive stone mines underlie the Bath suburb of Combe Down, and following initial surveys in the early 1990s, it became apparent that there was insufficient ground covering the mines to guarantee the safety and stability of structures built over them. This resulted in a successful funding bid by the local council for a land stabilisation programme, which would involve many areas of the mines being filled with foamed concrete, but as part of this programme archaeological recording prior to infill was included.

The recording work was carried out by Oxford Archaeology, and in areas that could be safely accessed conventional survey and recording techniques were used. However, many areas beyond the roadways, built to provide safe access during the infilling works, could not be entered by the survey team, and an alternative means of recording was needed. This was done by laser scanning, as the equipment could be safely placed in several closely-spaced positions just outside the roadways, allowing a composite picture not obtainable by normal survey methods to be built up. From this, plans, sections and three-dimensional images could be prepared (Willies et al. 2011, 308-309). In some cases, a borehole laser scanner was used, either cantilevered out into the dangerous areas to enable survey of areas not otherwise visible, or to survey completely inaccessible workings.

One consequence of this recording was that it was possible to create a virtual fly-through of the scanned areas, both in wire-frame (Lord 2010, DVD included in printed copy) and tinted images. The latter provides a highly accessible record of the workings, which is of great use as a public engagement tool, and to this end a DVD has been produced incorporating still and cine photography, as well as the aforementioned animated fly-throughs (Lorrimer 2011).

A further technique of note was used at Combe Down in order to recover miner's graffiti drawn on the sawn stone faces with coal "crayon". The surfaces were coated with silicone rubber, which was peeled off when dry removing the graffiti with it. This acted as almost a "negative image" which could them be transferred on to resin board, enabling public display of the graffiti (Willies et al. 2011, 6-17).

15.6 Discussion

Most scientific techniques used by archaeologists require specialist equipment and expertise which will be found either in academic settings or commercial archaeological units and laboratories; in contrast, much work on the archaeology of extractive industries is carried out on a voluntary basis by individuals or members of societies interested in industrial archaeology and history. Such non-vocational researchers may not be fully aware of the potential for scientific analysis to augment their work, or, more likely, the cost of engaging the relevant expertise and equipment puts most scientific analysis beyond their reach without external assistance. Secondly, the nature of the equipment used for many techniques means that using them in the field is difficult if not impossible, and so where material cannot be removed from its location it may not be possible to analyse it with the most appropriate method.

To date, there has also been an understandable tendency to use scientific techniques to answer questions about earlier mining/extraction where there are no historical records, or where evidence for the introduction of technologies has wider implications. It is possible that this is due to a perception among researchers that grant applications to fund scientific analyses are more likely to succeed if the extractive activity is believed to be early.

It is also noticeable that the use of scientific investigation tends to happen more on the remains and residues of secondary processing e.g. smelting, but such processes often leave remains in the archaeological record which are particularly suited to this.

16 A Research Agenda for the Archaeology of the Extractive Industries

Compiled by Phil Newman

16.1 Introduction

With the assessments completed and circulated, the next stage in the process has been to formulate an agenda based on its conclusions. As anticipated, this has revealed gaps in knowledge of all aspects of past mining and quarrying, and specific research will be necessary to fill these, but also it has exposed some more general concerns. As a specialised branch of the archaeology discipline there is underutilisation of techniques and resources, as well as shortfalls in skills, training and cross-disciplinary liaison. Furthermore, there is a general reluctance on the part of the wider archaeological community, to engage with the extractive industries as a focus for research, and by society at large, an appreciation of the value of the artefacts and landscapes as cultural assets is yet to be awakened. All of these factors have hindered progress and continue to do so. Therefore, the agenda comprises a range of research aims, agreed to be required. In some cases these are in pursuit of specific themes designed to improve our knowledge, and in others for improvements in practice within the discipline as a whole.

The process required to deliver an agenda has involved consultation with a broad spectrum of colleagues involved with, or with a common interest in, the archaeology of the extractive industries. Upon publication of individual assessments on the World Wide Web, feedback was received from, among others, mine and quarry specialists, historians, academics, independent researchers curatorial archaeologists and field archaeologists, all of whose contributions have been absorbed into the debate. Two seminars were held in 2012 - at Caphouse, West Yorkshire in the north of England and Sidcot, Somerset in the south - at which people from a range of backgrounds were able to express their views and offer suggestions for future research. Others contributed ideas and comments via email to the project officer.

The following aims, set out under thematic headings, have been agreed by the steering group to represent the main topics for future research. For each of these research aims (in bold) some background information, or ideas for actions, which could contribute towards achieving them, are added beneath. These ideas are not exhaustive and within each aim there is potential for additional actions.

16.2 Themes

16.2.1 General themes (RA 01-13)

Surprisingly, common themes suggested by many colleagues were not necessarily explicitly designed to address gaps in the data, but ways of addressing more general weaknesses in the infrastructure and national context within which contemporary research and conservation take place. This suggests that while many researchers have agenda priorities specific to their field of interest, they are also concerned for the overall health of the discipline, how it is perceived by others, and how it needs to be more widely recognised within conservation, planning, museums, archives, inventories and higher education. Therefore, many of the research aims are directed at these general themes, which, if implemented, would:

- attract greater recognition of England's mining and quarrying legacy amongst researchers interested in all periods of the past
- raise the profile of mining and quarrying archaeology in terms of its significance to the heritage and the national narrative for England and Great Britain
- raise awareness and appreciation of mine and quarry heritage assets among those responsible for planning and conservation
- engender a spirit of collaboration and dialogue between researchers, local authorities, landowners, commercial interests
- free-up the flow of data into inventories, such as county HERs, from a variety of researchers in the independent, professional and academic research sectors, and through publication
- increase capacity among heritage professionals and independent researchers.

Although these concerns were shared by colleagues across the spectrum of mine and quarry research, naturally, those involved with each specialism, be they researching a particular extractive industry, region or period, were also able to identify gaps in the existing data and suggest steps that should be taken. Within many of the material-specific topics there is commonality on the need to investigate issues such as earliest origins, the impact or otherwise of technology, sources of power, the potential for underground research, movement of materials and social context. For the metals, greater knowledge of extractive techniques, dressing, pumping, raising ore etc, are universal themes for which research aims need to be designed. However, for each material, there is a wide range of more focussed questions specific to periods, regional biases and anomalies thrown up by historical research.

16.2.2 Methodology

Landscape survey (RA 14-18) has a long tradition recording the evidence of past mining and stone extraction, and still has much to offer. A basic record of field evidence is lacking for much of the archaeological resource and fieldwork is needed on a massive scale to bring records up to standard. An increase in mapping-scale and large-scale surveys of earthworks, buildings and landscapes will be required to do this. The use of remote sensing, such as LiDAR, historic aerial photo transcription and assimilation of detailed historic mapping could also make a significant contribution.

Archaeological excavation (RA 19) could answer many of our questions about surface and underground evidence of mines, yet its use is confined mostly to planning requirements where sites may be destroyed. Research excavations are few and there is a need for more.

Underground recording (RA 20) is needed at the majority of accessible workings to increase our understanding of mine working techniques and conditions. A lack of researchers equipped with the necessary skills to undertake this work needs to be addressed through training, and it is essential that this branch of the discipline is expanded.

Scientific techniques (RA 21 - 23) used routinely in archaeological research elsewhere, have not yet been utilised to their full potential within the extractive industry field of study. Techniques for dating of mine workings, such as C14, and for the provenancing of ores used in artefacts retrieved from past archaeological activities, have proven track records and should be more widely applied with the context of mining industries. More work needs to be done to develop and adapt less well-known and less tried methods that will be useful in the specialised sphere of mine workings, particularly underground. Techniques with potential are listed below.

16.2.3 Raw materials

The assessment has demonstrated that there is an imbalance in the volume of past research undertaken between the different materials. This not only reveals biases in the priorities and preferences of researchers, but also variability in the opportunities to undertake research depending on the environment in which the remains are to be found and the degree to which historical material survives. Research has also been fuelled by situated groups pursuing research with a common purpose and focusing their efforts on a particular type of extractive evidence. Such groups are very unevenly spread across the spectrum of extractive archaeology. The corollary of this patchy coverage is that, for the industries that have a longer tradition of investigation, the research questions are more forthcoming and more focused, with better defined and specific goals. Whereas, for those industries for which archaeological research is in its genesis, the specific goals are less easily pinned down while an insufficient knowledge base exists. For these topics, more general aims need to be developed to answer basic questions.

Bulk minerals (RA 27-38) collectively, comprise the largest category in the assessment, including stone, sand, gravel, limestone and aggregates, but are the least well investigated archaeologically. Much effort has been expended on the study of stone artefacts, monuments and buildings, but, with the exception of prehistoric flint mines, little attention has been paid to the sources of these minerals, or whatever archaeological evidence may survive of their extraction. Among the different materials extracted, however, some niche interests have had more attention paid than others, including lime and millstones, although studies of the sources is still lacking for most types of stone, sand, gravel and aggregates.

Coal (RA 39-42) has benefited from a long tradition of historical research, directed particularly at the economic and social aspect. Although some archaeological recording is happening, it is on a small scale and nearly all development-driven, including rapid recovery. No regional or national archaeological research project has yet taken place and far more work is needed, while priority still needs to be given to sites under threat of destruction.

Much is known about **iron** (RA 43-48) smelting, particularly in areas such as The Weald and the Forest of Dean, but very little work has been attempted at early iron mines, such as the 'scowles' found in the latter area.

Later aspects of the iron industry in some areas are well covered by local histories but a national overview of the archaeology and resulting landscapes is lacking.

Clay (RA 49-51) is a ubiquitous material for the archaeologist. It is the source of all pottery, bricks and tiles, but little work has been done to study the sources of the material and the archaeology of its extraction except in the china clay areas of the Southwest.

Of the non-ferrous metals, **lead** (RA 52-55) has benefitted from the greatest variety of investigation, including a long tradition of historical research, archaeological recording of surface evidence, and underground exploration. Although mineralogically, and often geographically, closely associated with lead, **silver** (RA 53), **zinc** (RA 57) and **smithsonite** (RA 56) have received less archaeological attention. **Tin** (RA 58-60), although somewhat lacking in underground survey, has had the most effort applied in the recording of surface evidence and also has a well-researched historical base. **Copper** (RA 61-63) is perhaps the least understood and least researched of the non-ferrous industries, with site-specific exceptions. **Gold** (RA 64) was infrequently recovered in England but what evidence that exists, suggests further fieldwork could bring benefits

A number of **minor metals** (RA 65-68) and minerals have been exploited in England including **alum**, **antimony**, **arsenic**, **bismuth**, **cobalt**, **manganese**, and **tungsten;** their remains are widely dispersed, no national picture exists for any of them, and localised studies are few. A similar situation exists for **gangue minerals**, (RA 69-70) where retrieved as a secondary crop, including **barytes**, **fluorite**, **graphite, umber** and others.

For **salt** production (RA 71-72), archaeologists have focussed much effort on brine evaporation, with its origins in the pre-Roman period, whereas mined salt has had little attention paid to it.

Crosscutting research themes, common to several mineral industries at the point of extraction, include underground techniques, technology, sources of power and downstream processes or dressing, and may be recognised under many of the separate mineral headings below. However, some universal themes are more detached from the mining and quarrying, though essential to understanding the development of these industries, separately and as part of the industrialisation process in England/Britain. These themes include the social and economic impact of mining and quarrying, as well as infrastructure and transport systems (RA 75) and some aspects of prehistoric and Roman mineral working (RA 73).

16.3 Research aims

16.3.1 General

RAISING THE PROFILE AND FOCUSSING RESEARCH

Research Aim 01: Raise the profile of the extractive industries as a field of study within British archaeological research and conservation, and encourage wider involvement.

a. From earliest times, life and culture in the British Isles has been bound up with the exploitation of mineral resources. People's ability to recognise the potential of, and exploit, these resources has had a major impact in shaping the material output of society. All physical forms of human expression require materials, many of which have to be mined or quarried, and much human intellect, resourcefulness and labour has been expended on procuring them. This should place the extractive industries amongst the key themes at the forefront of our efforts to understand past societies. Unlike many of the established themes within British archaeology (e.g. settlement, urbanisation, security and defence, religion and farming) mining and quarrying are less often the focus of study and are frequently overlooked in general works of synthesis despite being a key surviving component of the historic environment, and crucial to any study of material culture from the past four millennia. The significance of a vast range of artefacts, from jewellery, through tools and everyday structures, to high status buildings would be far better understood if the technological, social and economic processes involved in procuring the materials could be more fully grasped.
b. Extractive sites and landscapes are infrequently considered within an historic environment context when management or planning decisions are made and, in the past, have been more likely to be viewed in the context of derelict industrial brown field sites in need of remediation. The results of research need to be used to inform conservation, management strategies and planning proposals affecting extractive sites, so that decisions can be made which are appropriate to the cultural significance of mining and quarrying landscapes, sites and buildings. To achieve this, it is not only necessary to raise the profile and level of research, but also to raise awareness that evidence of extractive activity is a fundamental and inherently interesting component in our understanding of the past, and a cultural

resource in its own right. Therefore, equal weight should be given to mine and quarry evidence as to any other form of archaeological site under the heading of historic environment.

Research Aim 02: Target archaeological research towards all aspects of historic mining and quarrying in England, to enhance what is known and fill gaps in knowledge (*see also* research aims associated with raw material themes below).

a. More research-led archaeology is needed into all aspects of the historical extractive industries in England using as wide a range of methods as possible. The major mining industries have all been well served by historical research, albeit selectively, but archaeological research has lagged behind. Much remains to be done through basic recording and targeted investigation, and many of the questions that remain to be answered would be better addressed through a synergy of archaeological, geological and historical methods.
b. It is necessary to look beyond the site-specific, localised or regional spheres of research into mines and quarries, and to place the results in much broader contexts, including National, European and World perspectives. The archaeology of the extractive industries also needs to become more integrated with other cultural and temporal themes within British archaeology (*see* RA 01).
c. Archaeologists investigating mines/quarries and mining/quarrying landscapes should be encouraged to extend their research beyond the material evidence and integrate other forms of data, including environment (geological and topographical), and historical context (economic, political and social).

Research Aim 03: Use archaeological and historical research to establish similarity and difference at regional level, beyond the distribution of raw materials, and develop this data to propose a more complete national picture for these issues.

a. Regional, chronological and technological variations in the exploitation of similar mineral sources are poorly understood. Such variations include the sources of power adopted (water, steam, animal, other) and varying demands in consumption (locally and nationally), as well as economic constraint, and the differences forced by environmental variation in geology and in natural resources. Such variables have influenced the archaeological footprint to be expected at any one place and a better grasp is needed of the facts that lie behind them.
b. The adoption of state-of-the-art technology, in preference to continuing with traditional methods, and vice versa, needs to be explored for all extractive industries. Was the former adopted only when the latter became impractical or too expensive? Is there any regional basis to such decisions? How might outside influence from elsewhere in the UK or worldwide, Germany in the 16th century for example (*see* RA 62), and the USA in the 19th, affect the adoption of new technology?
c. There is a range of cross-cutting variations and commonalities between different mining and quarrying processes used for extracting different raw materials. These include: prospecting; extraction by hand, firesetting or explosives; raising ores from depth; the problems and opportunities presented by water, such as ore dressing and the adoption of pumping machinery; whether simple machines and processing equipment are used widely across a mine or quarry, or conversely whether more expensive plant led to centralised processing; the impact of mines at their peak in influencing population and transport infrastructure, where and how miners lived and whether special provision was made for them (*see* RA 74).
d. Historical mines and quarries have varied in scale from large successful enterprises, through spectacular failures, moderate though enduring producers, small-scale local enterprises, to unsuccessful trials. Similarly, some ventures were well-financed and able to invest in the latest equipment and/or infrastructure or long-term mine development, while others were operating from day to day on a shoe-string. Researchers need to establish which factors apply to the sites they are investigating.

Research Aim 04: Promote the compilation and maintenance of comprehensive inventories covering mining and quarrying heritage assets.

a. Prioritised inventories are necessary to raise the profile of what is significant within the heritage of the mining and quarrying industries, to encourage better informed conservation, and to provide the data needed to carry it forward; also, to provide the baseline data needed as a point of departure for future research.
b. Inventories are needed at a basic level within individual research projects, and within the county HER structure and should be mutually transferable. Mines and quarries often form large and complex

landscapes, comprising many and diverse assets, including portable artefacts (*see* RA 11 & 12), each of which needs considering individually in terms of location, description, interpretation, relationship with other assets and dating. Grouping sites as a single asset diminishes the significance of both the assets and the whole, and should be avoided. This should apply not just to mine/quarry themed recording projects, but also where landscapes undergo a programme of general multi-phase and multi-themed recording.

c. It is important that a strategic view is taken and that priorities, significance, terminology and other common themes within inventories are agreed at national as well as, regional and local levels.
d. For bulk minerals, a useful strategy will be to identify specific resource zones across England, based essentially on geological zoning, but taking other factors into account; these are necessary to break the resource down into manageable groups and to assign standardised typolgies.

Research Aim 05: Establish a mutual awareness of, and mechanisms for liaison between, HER officers and independent mine researchers who possess information or expertise.

a. In the field of mining and quarrying archaeology, independent researchers are very active and often highly knowledgeable, especially at local level. Some HERs have already benefited from the contribution of these researchers; however, the mechanisms for facilitating this input of data need to be improved, for many researchers are either unaware of, or believe that their input would not be valued by, HERs. Conversely, HER officers who might welcome the input, may be unaware of who possesses the knowledge of these topics, much of which is unpublished or resides within publications with which they may be unacquainted. Some form of liaison between independent organisations, such as those affiliated to NAMHO, and HER officers, either at county level or via ALGAO, would be beneficial in creating a flow of data to HERs for the whole of England.
b. Improved channels of communication between people well versed in assessment of historic mining and quarrying and HERs are needed. HER officers could be provided with contact details of individuals or organisations willing to advise on various industries or on the significance of field remains, particularly in advance of development.
c. Guidelines need to be established and disseminated to address the question of quality control and verification of material presented for input. Researchers need to know precisely the format of electronic data required for HER databases and the types of paper records and reports suitable for archive. This may need to be done on a county basis to conform with the variety of systems, protocols and polices in place, but an over-arching national strategy is desirable.

TRAINING, CAPACITY BUILDING AND HIGHER EDUCATION

Research Aim 06: Improve opportunities for capacity building and training in both the professional and independent sectors.

a. The level of understanding of mining and quarrying landscapes generally, is not as well developed among professionals archaeologists as for other aspects of the historic environment. This applies to those working in archaeological organisations and companies involved in pre-development, as well as curatorial archaeologists and those managing archaeological projects in the commercial sector. Such knowledge is essential for informed interpretation and evaluation of earthwork evidence, standing structures, underground remains and industrial landscapes, which are under ongoing, and in places, increasing threat. Ideally, a basic grasp of this knowledge needs to be instilled at undergraduate level and while this may be addressed long term through the higher education system (*see* RA 07b below), there is also a need for workshops. These should be aimed at broadening the knowledge of professionals as part of their continuing professional development (CPD), thus increasing the number of practitioners competent to make decisions involving disused historic mines and quarries, including underground evidence.
b. Training should be more easily available for workers in the independent sector who may require instruction in archaeological techniques and standards such as field recording, measured survey, geophysics, procedures and protocols regarding uncovering and consolidation of sites and structures, documentary research and use of HERs (*see* RA 05). More community archaeology events and training projects could help with this, but training might also be provided by those organisations whose mandate it is to provide adult education opportunities.
c. There is a need to provide geological training for archaeologists involved in mining/quarrying-themed investigations and excavations. Many professional archaeologists called upon to investigate such

remains have no training in geology, although knowledge of it can be critical in understanding how these sites developed and functioned. Better channels for liaison and collaboration between those knowledgeable in geology and archaeological practitioners need to be opened and maintained.

Research Aim 07: Encourage greater research involvement into the historic extractive industries by the higher education sector.

a. With only a very few exceptions, the higher education sector has been slow to engage with industrial themes generally, including mines and quarries. This omission is a major defect in the design of British undergraduate and post-graduate courses in archaeology. The result is that few archaeology graduates have knowledge of these topics, and that the inherent biases among graduate practitioners as to what is, and is not, of cultural value, seldom allows for mining remains to be perceived as significant. This situation continues, despite the increasing expectation for trained professionals within central and local government, and commercial units, to advise on planning decisions or carry out investigations, assessments, and excavations at post-medieval and modern archaeological sites, including those related to the extractive industries.
b. The archaeology of extractive industries, in conjunction with other aspects of the industrial past, needs to be better recognised and introduced more widely into undergraduate archaeology courses, in the same way as other key elements of human existence, including farming, settlement, communications, defence and religion, are already included.
c. At post-graduate level, Masters courses offering vocational training in heritage resource management, archaeological landscapes and the built heritage, should be further developed to cater for the demand for future curatorial professionals with knowledge of mining and quarrying archaeology. Specialist Masters degrees or diplomas aimed at continuing professional development (CPD), focussing on research and heritage management of the extractive industries could also be developed separately.
d. More encouragement is needed for mining and quarrying archaeological topics to be researched at doctoral level; for this to happen, increased supervisor capacity among academics is needed. Period and themed research or methodological and theoretical topics covering historic extractive industries, are an underdeveloped field for investigation.

COLLABORATION AND DIALOGUE

Research Aim 08: Establish and encourage a culture of collaboration between professional and independent researchers from various research disciplines, local and central governmental organisations, and other UK areas (Scotland and Wales and beyond), with a common interest in researching, promoting and conserving Britain's past mining and quarrying resources.

a. Links need to be forged or, where existing, strengthened to promote liaison between researchers in England, Wales, Scotland and Ireland. Most of the research questions that need to be asked about the coal, non-ferrous metals and quarrying industries in England could be applied to Scotland or Wales. Liaison and collaboration is a way of sharing knowledge and expertise, and promotion of a UK wide interest and awareness in the topic. Similarly, there is much to be learnt through collaboration with researchers at an international level. For example in respect of bulk minerals, liaison through the recently formed European Quarry Landscapes Network and the Global Heritage Stone Resource initiatives should be encouraged.
b. In Britain, the interests of mining researchers are represented by a diverse and diffuse set of organisations at local, county and thematic level. Several societies have also taken on the mantle of regional representation or advocacy for these interests, such as the Peak District Mines Historical Society (PDMHS), Welsh Mines Society (MWS), Northern Mine Research Society (NMRS), Trevithick Society. NAMHO acts as a central hub for all such groups in Britain, and inter-regional contact is encouraged through an annual mine-history conference. However, there is no effective central, cross-disciplinary, pan-regional forum to share ideas or provide up to date information on a regular basis. We need to forge better links between the regional societies and county archaeologists and their HER officers, so that society members make inputs to HERS as a matter of course (*see* RA 05)
c. More mining historians need to be engaged with the archaeological process. Communication between mining historians and archaeologists needs improving and perception as to methodologies, scope and product from each discipline needs to be clarified. A cross-disciplinary approach would be more productive in many scenarios.
d. Networks, or lists, of regional mine and quarry specialists from all relevant disciplines willing to be included as consultants, would greatly assist in

cross-disciplinary collaboration.

e. There is a need to develop collaborative projects involving archaeologists and researchers from other disciplines including regional geology; industrial, economic and social history; historical geography; archaeological science and others.
f. Similarly, to ensure different aspects of the historic extractive industry resource are properly considered, there needs to be greater links forged between organisations such as Historic England, Natural England the British Geological Survey. and the Department for Communities and Local Government. The differing interests of these bodies can sometimes impact in a negative way on the welfare of fragile archaeological remains at mine and quarry sites.
g. One of the specific aims arising from (f) should be the establishment of protocols to ensure a proper balance in decision-making between biological or geological conservation, meeting the demand for new materials (especially for stone) and protecting industrial archaeological interests.

Research Aim 09: Build a dialogue between the historic environment sector and active commercial mining, quarrying and clay working companies, and with regulating bodies such as the Coal Authority and the Mines Inspectorate.

a. Modern mining and quarrying companies often have an interest in the heritage of their own industry, and, by increasing awareness, should be encouraged to facilitate research and fieldwork beyond that required by planning conditions, in advance of destruction of earlier industrial features, and removal of redundant plant from their sites. An attitude of encouraging investment in their 'archaeology of the future' should be fostered. There is potential for companies to become active in assisting with investigation and research within their working sites. Although companies may be by nature reticent about disclosure on such issues of expansion and other developments, appropriate dialogue between the professional historic environment sector or via the independent sector (NAMHO for example or local research groups), well in advance of quarry or waste dumping extensions, could bear fruit. This might usefully be initiated by dialogue through the UK Minerals Forum and in turn via the respective trade associations, the Institute of Quarrying and the Planning Officers' Society.
b. Benefits would include advance warning of developments that might threaten current or historical artefacts, buildings, earthworks or buried features related to the extractive industries, and allowing adequate time to properly record, excavate or remove items under threat.
c. Companies, or their representative trade bodies, may be willing to provide resources (financial and logistical) to help with recording the heritage of their own industries.
d. In the case of incidental discovery of organic artefacts within, for example, old coal mine levels exposed during opencast operations or other developments, intervention by appropriately qualified conservation staff is needed at an early stage before degradation sets in. Mine managers and contractors need to be made aware of the need for urgency.

Research Aim 10: Encourage landowners and local authorities to value mine and quarry remains on their land or in their area/county as heritage assets rather than a threat to public safety.

a. Mining and quarrying remains are often perceived by landowners as unproductive derelict land or dangerous hazards to public safety in need of 'improvement'. Comparatively few mining remains are listed or scheduled, or within environmental stewardship agreements, and this often leads to misguided decisions to either fence the sites and forget them, allowing and promoting vegetation to completely engulf and threaten the stability and integrity of the remains, or the demolition of buildings, filling of shafts and flattening of spoil heaps. Shafts are often capped in such a way as to render them completely inaccessible, without assessing their historical significance. More conservation-friendly methods are needed for retaining sites under threat, either through existing designation and agri-environment channels, or through proactive dialogue that extols the value of such features.
b. Mechanisms need to be established, or further developed, by which unbiased archaeological advice as to significance and value of specific mining and quarrying remains is made available to landowners; similarly shaft capping guidelines and information on other conservation-friendly solutions to solving issues need to be made more readily available. Site management, including appropriate public safety solutions, could then be properly informed with conservation in mind. With sites that are designated by Historic England and/or Natural England, or are in agri-environment agreements, all proposed actions need to be discussed with the relevant specialist organisations.
c. Pressure needs to put on local authorities, and

others, to consider open shafts and adits as providing important access to underground heritage assets, rather than public safety legislation being the only consideration. Sensitive solutions should be sought where both considerations are met positively. Where it is necessary to seal mine entrances for reasons of public safety, this should be done using methods that do not prevent future underground archaeological investigation.

d. Where it is necessary to treat abandoned workings in order to stabilise the surface, as in the case of shallow underground stone quarries or coal workings, particularly where open shafts or adits survive, work should be preceded by an archaeological assessment with the option to fully record features prior to remedial action.
e. At the very least, where any mining or quarrying remains are to be altered or effaced by unavoidable safety-driven work, opportunities for recording affected areas need to be made available, and those commissioning such safety works should be made aware of the need to undertake such recording.

MUSEUMS AND ARCHIVES

Research Aim 11: Integrate the museum sector more fully with the archaeology of mining and quarrying at national and local level.

a. Museums should be a research resource; future fieldwork may result in more artefacts, and museums will need to curate these collections. A collecting policy and guidelines should be developed for the mining and quarry archaeology sector, where large artefacts may result from excavations and rescue projects. Researchers should also give due consideration to archiving their own research findings, especially drawings, photographs and documentary resources.
b. The interests of the mines and quarries sector should be better represented and fully integrated into future national museum strategies.

Research Aim 12: Better information is needed as to what relevant material survives in museum collections nationally. A national survey is required, following on from which, the material could be studied on a typological basis to confirm its relative date and rarity.

a. Coal mining in many parts of the country (whether deep mines or opencasts) has incidentally uncovered many artefacts from earlier mining periods. In most cases these were isolated finds curated with little or no contextual information beyond the location of the mine and perhaps the name of the seam of coal. They were often brought off site by one of the mine managers, so would already be drying out and deteriorating even before they were seen by a museum curator.
b. Attempts by local curators to understand the function and date of such finds have often only been based on patchy and incomplete documentary records. Sometimes photographs or drawings were taken and notes made in local historical journals. In most cases the museum staff concerned would have had little, or no, experience of dealing with material from old mines, either as regards understanding an artefact's function, or knowing how best to record and preserve it. Nevertheless, anecdotal information suggests that many items were kept, and may survive in museum stores.
c. Material could be studied on a typological basis to confirm its relative date and rarity. This would allow the creation of a national inventory (*see* RA 04b), establishing the existence of surviving artefacts, widening knowledge of their existence for future studies, and enabling some assessment to be made of their rarity and importance at a time when many museums are closing and even considering the disposal of their collections.

Research Aim 13: Undertake a renewed survey of (quarry) company archives; establish a central register of related collections and encourage an open policy of researcher access and/or deposition of archive material into public collections by quarry companies.

a. The last 50 years, and particularly the period since 2000, has witnessed a series of industry-wide mergers and a consequent dispersal, or severe loss, of archival material. Many of these papers, very few of which are currently publicly available, are potentially invaluable to our understanding of the industry's past. Unlike coal mining, there is no mandatory requirement to file quarry plans after abandonment. Furthermore the unprecedented recession in the industry after 2008, has resulted in probably the greatest number of site closures since the 1930s. Written records often provide the only clues as to the location and nature of sites, especially for building and industrial stone suppliers.

b. The survey of company archival material conducted in 2000 (sponsored by the Institute of Quarrying - IoQ) needs to be reviewed and updated. A central register of related collections needs to be established. The embryo collection of quarry archives at the National Stone Centre needs to be more widely publicised as a dedicated repository, and developed to a level comparable to that for coal at the National Coal Mining Museum. Special attention needs to be directed towards capturing film footage. In this respect, stone investigation reports prepared for conservation purposes (often funded by NE, formerly EH) should also be deposited and held centrally.

16.3.2 Methodology

LANDSCAPE AND SURVEY

Research Aim 14: Establish, as far as is possible, the landscape impact of the extractive industries for all periods in England.

Essentially, mining is an underground process and the recording of surface evidence alone cannot adequately inform us of the extent or importance of mines. Nevertheless, surface expression is often the only obvious evidence available for mining activity, and, combined with the remains of processing, dressing, transportation and infrastructure, has made a substantial impact on the landscape in many parts of England. The same is true for many opencast mines, quarries and claypits, which have, in places, significantly re-shaped the landscape. However, the extent of the activity has often not been collated and it has not been possible to make even approximate statements about the significance of this collective resource in the same way as we may be able to do for other themed studies. While some progress in specific regions (as with metal mining in the Peak District and in Cornwall) a national audit is required, not only to record the landscape evidence of the extractive process but also to explore the historical geography of associated settlement and dependant industrial processes. This would most easily be done on a county by county basis, or preferably by mineral resource area, building on and augmenting existing HER databases and other thematic inventories (*see* RA 04). Full use should be made of the following resources and methodologies as a means of gathering data for all of England's extractive industries:

- published accounts and site histories, printed and online
- existing archaeological surveys and reports on earthworks and structures
- unpublished documentary evidence available from county and national archives
- early mapping – large-scale 19th- and early-20th -century OS maps contain a wealth of data, which needs systematic, detailed transcription on a county by county basis. Use map regression to study the impact of past extractive activity on the modern landscape
- Historic Landscape Characterisation (HLC) data, where available
- railway and canal research for understanding transport infrastructure in particular
- aerial photo transcription. The National Mapping Programme has produced much data on the extractive industries, particularly early outcrop workings, and underground workings with extensive surface expression
- utilise currently available and future LiDAR data sets as a means to record the landscape impact of the extractive industries (*see* RA 17)
- make use of GIS for collation and presentation of results.

Research Aim 15: Expand the survey record of standing buildings, surviving ruined structures and earthworks associated with the mining and quarrying industries, including measured survey and an increased use of digital photography and other digital techniques for data capture and archiving.

a. This applies to all extractive industries where standing and ruined buildings, other structures, extraction opencuts, quarries, and earthworks survive. In most counties, for most aspects of the mining and quarrying heritage, the record of what remains is far from complete, and, in many cases, not even a basic archaeological record has been compiled. Priority needs to be given to buildings and structures/earthworks threatened by development or neglect, but all examples and all aspects of the resource need to be recorded.
b. Surface survey should, if possible, follow the levels and standards set out by Historic England (EH 2007). Where resources allow, a high level of analysis and interpretation should complement the surveys, and be archived alongside plans produced.
c. Where possible, digital technology, in initial data capture, and/or archiving, should be encouraged. This will require national and local strategies for presentation of data, selection of images and archive curation.
d. Independent researchers should be encouraged to carry out field survey in whatever ways are available

to them and to publish the results in journals, books, websites and/or through deposition in the HERs.

e. Training in a wide variety of survey and other data-collection methods should be offered to researchers, to facilitate data acquisition for the benefit of their own research and input into HERS. This training should go beyond how to use survey equipment and needs to include the observational and analytical skills required to recognise and interpret earthworks, structures, and underground workings (*see* RA 06b).

f. Particular aspects of the mining resource are currently under-recorded. Within each region or mineral topic, the evidence of certain activities, processes, infrastructure or social themes has dominated the archaeological research of the past, leaving other aspects under-represented in the body of published works and within inventories such as HERs etc. Neglected areas and topics (*see* research aims for mineral categories below) need to be identified and the standard of record enhanced. This task would become easier if a policy of compiling inventories recommended in RA 04 is widely adopted.

Research Aim 16: Record the surviving evidence of modern mining and quarrying while there are still opportunities to do so, and document the memories and knowledge of the people involved.

a. It is ironic that while much that was in use in the late 20th century was systematically eradicated, the remains of earlier mining, from the origins to the mid-20th century, are more plentiful (if no longer common when compared with what once existed). For the coal and bulk mineral industries in particular, photography and other methods of graphical recording should be used, together with oral commentary from ex miners and quarry workers, to make a record of any standing surface structures and other infrastructure, such as welfare facilities and housing. Priority should be given to threatened or highly derelict structures and sites omitted from the 1990's RCHME and EH surveys of the coal industry.

b. Similar levels of survey and recording are needed for other 20th- and early 21st-century extraction sites, where they are still active or recently abandoned; for example, where gangue minerals have been mined or where materials such as stone, gravel or clay have been extracted at surface. Ideally, structures should be recorded before they are removed under 'restoration' schemes and while their use is still fresh in the memory. All too often, oral recording has confined itself to social history, working conditions, etc; for the archaeologist this could be usefully complemented by descriptions of equipment, structures and their purposes.

c. With places and structures still in use for mining and quarrying, (as noted above in RA 9), protocols should be established in agreement with the extraction industry and mineral planners, that will allow, or in certain cases require, recording of structures as a matter of course in advance of them being removed or abandoned, or in advance of 'restoration' implementation.

Research Aim 17: Make more use of LiDAR and other aerial reconnaissance techniques as a means of recording surface evidence, discovery of unrecorded sites, and as an aid to the interpretation of field remains.

a. LiDAR has become one of the key remote sensing techniques to be used for reconnaissance and map-scale recording and it has potential to assist with general analysis of landscapes. Although this technique is able to reveal very subtle traces of human activity such as feint earthworks, it also has the capability to show in great detail, the more robust features of extractive landscapes, such as spoil heaps, tramways, leats, shaftheads, outcrop workings, building footprints, opencasts, working faces and tin streamworks. The product can include geo-referenced, three-dimensional, map-scale transcriptions. As many surface features of mines and quarries have never been accurately plotted, and as more LiDAR coverage becomes available, it should enable rapid recording and mapping of some extensive areas of extractive activity.

b. So far, LiDAR data has been utilised mainly by professionals working within governmental organisations, universities or on commercial landscape projects. Currently, the cost of the data, and the software needed to fully utilise it, is too high, for most independent research projects. Ways need to be found for these data to be more easily available to the mining archaeology community, particularly high resolution data.

c. Where national or regional projects are developed to record landscapes from LiDAR or aerial photography (the National Mapping Programme for example), extractive landscapes need to be considered an equal partner along with other forms of past human intervention. This means that an equal level of expertise and resources needs to be directed at the interpretation and analysis of mining and quarrying landscapes, in preference to them being

considered as areas where other archaeology has been removed. As part of the assessment process it is important to plot areas that are genuinely sterile because they have been opencast and then backfilled and to ensure that this information is provided to HERs.

d. Historic aerial photographs, available mainly from the 1940s onwards, have the potential to depict components and features of the mining landscape since swept away by more recent development, changed through neglect, or now enveloped by scrub/tree cover. They also depict many aspects of the countryside and urban landscape that remain unchanged. More use could be made of this resource, and that of satellite images such as Google Earth, to help identify locations of key mining features and help with their interpretation.

Research Aim 18: Increase our knowledge of how mining and quarrying have impacted on other aspects of human activity in the landscape, such as agriculture, non-extractive industries, urbanisation, transport infrastructure, security and defence, monasticism.

a. Extractive activities exist as a part of wider cultural landscapes. No matter how isolated or expansive the mining or quarrying evidence may be, the activity and its location would certainly have affected or have been affected by other aspects of human intervention, directly or indirectly. For example, miner-farmer relationships are a common theme in several regions of England in the medieval and post-medieval period, but may extend back into the prehistoric period. Landscape research on this theme has borne fruit in the North Pennines and certainly would do if pursued elsewhere.
b. Industries frequently grew up around the sources of minerals, either to utilise the products of the mines and quarries or to supply the goods and services needed. Such industries and their infrastructure, including transport networks, have also left an enduring impression on the landscape (*see* RA 75).
c. The need for security to protect valuable mineral resources is a theme relevant to the ancient and more e recent past. Roman camps, and possibly Iron Age fortifications and some medieval castles were built close by certain mines as a means of controlling resources. More work is needed across all periods to establish such links.
d. Monasticism was influential in the growth of some mineral industries up until the dissolution in the 1530s. Frequently, abbeys and priories possessed control of large areas of land, including mineral rich areas from which wealth could be derived. The monasteries held a large interest in the Yorkshire and Somerset lead industries and research in Scotland has confirmed monastic control of many other industries including gold, iron, silver and salt.
e. Urban landscapes often grew up around the exploitation of mineral deposits, although the evidence has sometimes become lost after abandonment of the industry and massive growth of the towns. In the Black Country, for example, the once prosperous coal, iron ore and clay industries have become disguised amongst 19th- and 20th-century urbanisation. Landscape techniques, such as Historic Landscape Characterisation (HLC) and map regression can help establish the original extent of such industries and identify their influence on the growth and character of an area. These may also help pinpoint surviving feature of potential interest.

EXCAVATION

Research Aim 19: Increase the understanding of all types of mineral extraction and associated sites by making greater use of archaeological excavation. (*see also* individual research aims associated with separate raw materials)

a. Despite the huge potential for research excavations to enhance perceptions of the extractive industries of all periods and types, as yet they are uncommon. Also, much of the recording of these industries stipulated as preconditions within the planning process, is restricted to assessment or survey of surface evidence, while excavation, especially of 19th- to 20th-century sites, is rarely included in such conditions. Research excavations, on all but the most significant of sites, are yet to become commonplace, especially as part of large-scale enduring projects. Much more excavation is needed if knowledge is to be advanced in line with other aspects of the material past.
b. For mines and quarries operational in the historical period, excavation can often address questions that cannot be resolved from documents alone. These include aspects of chronology, and the provision of detail overlooked, or lost, in the historical records. Written material may be misleading or deliberately biased, and excavation(s) can provide a more accurate understanding of the past. Also, targeted excavations will provide more nuanced data to complement the limited interpretation of field

remains, such as buildings and earthworks.

c. Assumptions may be inadequate if based on poor or misleading documentary evidence or the information shortfall inherent in earthwork survey, geophysical survey and other forms of investigation. Archaeological excavation can test such assumptions
d. For earlier periods, field remains may survive, though they are less visible to the archaeologist, and are much less likely to be documented in anything but the broadest of terms, though mostly not at all. This is relevant to the Romano-British, Dark Age and medieval periods, but particularly so for prehistoric mining and quarrying. Although with the last, the balance has been redressed to an extent through archaeological research for some types of extraction sites such as those for flint and copper. For the post-medieval and modern periods, documentation may be lacking and excavation offers the only opportunity to investigate these operations.

UNDERGROUND ASSESSMENT AND SURVEY

Research Aim 20: Increase our knowledge of underground mineral extraction by encouraging, and resourcing, more archaeological investigations.

a. Although the majority of metals and coal, and a proportion of bulk minerals, have been mined using underground methods, the underground environment remains the least well archaeologically investigated sector of England's extractive industries. There are good reasons for this: the specialist skills to combine underground exploration with archaeological recording are currently possessed by only a few, and carrying out archaeology underground can sometimes be extremely arduous and time consuming. For the coal industry, underground exploration is strongly discouraged on the grounds of public safety. Ironically, whereas only a minute proportion of bulk minerals has been won by underground techniques, in this field, mining evidence is generally far better recorded than surface working
b. Where still accessible, underground mine workings must lie at the heart of any attempts to explain the resource. Frequently, there is valuable archaeological data here that cannot be obtained from the associated surface archaeology. The more impressive, accessible workings have an inherent character that tells of the importance of mines and the difficulties encountered by miners. What they can evoke in people who visit, makes them a resource of great value.
c. The profile of underground work within the archaeological mainstream needs to be raised, and researchers encouraged to see the potential and engage with exploration, recording and interpretation. However, professional work underground can often only take place under relatively benign conditions; there are some places that are entered by mine explorers as part of leisure activity, where safety restrictions in the context of paid work would be restrictive. Thus, an additional way forward is to build stronger links between archaeological curators and mine explorers. While it would be inappropriate to encourage people to enter places that others might consider dangerous, because of inherent instability of some workings, it should be recognised that there are people visiting these places anyway, often with the necessary skills and experience to do so in relative safety, and who have knowledge that might be usefully imparted. This approach has already been adopted very positively by Historic England with marine archaeology, and by Natural England in reviewing condition at underground SSSI's and monitoring bats, for example.
d. In assessing underground remains in detail a starting place is often survey. However, there is also a place for carefully targeted keyhole archaeological excavations to answer specific questions, and for employment of sampling strategies; for example to examine mine passage sediments and their mineral content, or to acquire radiocarbon dating material.
e. Underground remains need to be properly evaluated when they are to be affected by planning developments or other damaging operations. Where practicable, this should include detailed archaeological survey and interpretative appraisal.
f. Training opportunities in underground recording techniques are needed if this area of research is to expand. Modern recording techniques should be utilised and developed for use underground, including laser scanning, 'total station' surveys, rectified digital photography, and three-dimensional presentation of results. At the same time, it must be recognised that in some mines these methods cannot be employed easily, or that many of the people doing the recording will not have access to expensive equipment; thus, simpler ways of working should also be encouraged and training given.
g. Methods of constructing digital 3D underground models should be developed as an aid to understanding complex ore bodies and their relationship with surrounding geology and associated mine workings.
h. While there have been significant advances in the practice of underground archaeology in England,

there is much that might be learned from co-operation with practitioners in other parts of Western Europe, particularly France. A programme of co-operation should be initiated, which allows local archaeologists and mine explorers to experience the depth of expertise available across Western Europe.

i. Underground archaeological investigation of mines and quarries in England is led by voluntary sector interests. A system of agreed participation, perhaps involving demonstrable archaeological competence, is required between this sector, academics and government agencies, allowing the former a greater role, working in partnership with others in the investigation of abandoned mines and quarries.

SCIENCE

Research Aim 21: Take advantage of scientific dating and analytical techniques, to increase knowledge of prehistoric, Roman and medieval period mining and quarrying, but also develop techniques relevant to the analysis of later period mining, quarrying, dressing and smelting methods.

a. **Chlorine 36** was used by Bowen (Bowen 1994; Bowen et al. 1994 to try to date the first exposure of Stonehenge bluestones to solar radiation in order to prove that these could not have had a glacial origin. The validity of the results of this work has been much debated but this technique could prove useful in the dating of ancient exposed quarry faces. More research is needed into improving this and other cosmogenic isotopic techniques.

b. **Uranium series dating** has been used, for example, to help date the calcite speleothem sealing Bronze Age mining waste (deads) underground on the Great Orme (Wales). The technique is not widely used in mines, but has significant potential for use in ancient mining hosted within limestone rocks in England.

c. **AMS C14 dating** is the standard technique for dating ancient mine workings from Prehistoric to Early Medieval period and also for dating lead smelting boles and other ferrous/non-ferrous metal smelting. It is also possible to date bloomery iron by extraction of microscopic charcoal. AMS C14 dating is regularly used in archaeological dating projects, but only recently has it been applied to the dating of prehistoric metal mines in England (Timberlake & Marshall *forthcoming*) and to post-medieval firesetting (Barnatt & Worthington 2007). There is no reason why the use of C14 should not also be applied routinely to early historic and medieval period mining as routine.

d. **Dendrochronology** has potential in the dating of (for instance) ancient pit props. Timber was used widely in mining contexts both underground and to construct surface structures, so it is likely that with careful searching suitable samples could be retrieved. However, the technique is problematic as much of the timber used in mining areas does not conform to the studied sequences, and there is the problem of sampling from waterlogged timbers. Nevertheless, attempts to develop the techniques could be worthwhile.

e. **PXRF for the chemical analysis of soils** is a very effective tool for locating the presence of buried mineral spoil, and for determining the probable mineralogy/ metals worked at mines and smelting sites (e.g. in Wales the Bangor Leverhulme 1996 rapid reconnaissance mapping of the Great Orme for copper; Banc Tynddol Roman/Medieval lead bole smelting). Now regularly used as an archaeological field tool, it has great (yet still under used) potential for prospecting for ancient mines and smelting sites.

f. **Stable Isotope Analysis** is a technique which has some potential for provenancing the source of the metals used in a large range of artefacts. The element most likely to produce results is lead, but traces of lead are found within other metals, including tin and copper, so its use may be transferable. Lead isotope analysis requires reliable data from mine sites in the form of ore samples recovered from appropriate horizons, along with metal prills recovered from discrete, locally defined smelting sites. Little has been done in the area of ore analysis since Rohl's work in the 1990s (Rohl & Needham 1998) and no work at all appears to have been carried out on smelting residues. Action is required to rectify that shortfall. In some instances, study of the isotopes present in metal artefacts may prove revealing if they were manufactured before the metals in question were widely reused and the isotope content became mixed; for example the earliest Bronze Age copper objects, or perhaps medieval silver coins,

Research Aim 22: Improve the effectiveness and relevance of scientific techniques by promoting dialogue between mine researchers and scientists.

a. Scientific methods aimed at mining archaeological issues are often carried out within a scientific research context rather than an archaeological one. The scientists therefore, could be asking the wrong questions and misinterpreting the results of otherwise excellent science. Results must be integrated with current knowledge, and with up to

date archaeological and historical research contexts, to make best use of science in interpretation. Mine explorers and landscape archaeologists need to be trained in what scientific techniques are available, and how they might be useful, as well as instructed on correct sampling techniques.

b. Standard suites of scientific sampling techniques (*see* RA 21) suitable for use at mining sites need to be developed, and series of relevant questions devised, as a collaboration between scientists and mine researchers**.** For example, the Ancient Monuments Lab at English Heritage carried out radiocarbon dating on the kindling used to light coal used at underground firesetting sites; this proved that the firesetting was commonly employed in the 16th and 17th centuries AD (Barnatt & Worthington 2006; 2007; 2009).

c. In 1973, the NCB Laboratories aided NMRS by doing a palynological analysis of coal found on a lead smelting site and from surrounding coal mines in order to establish the source of the coal. Science based methods of these types need to be built into project designs and appropriate allowances to cover the cost of the work need to be included in funding bids.

Research Aim 23: Make more use of mineral samples within finds assemblages from prehistoric sites close to pigment sources as a means of scientific provenancing.

a. Prehistoric and later extraction of mineral pigments has been poorly researched but holds considerable potential for investigation, specifically in the field of provenancing using scientific techniques. Finds assemblages from Mesolithic and later sites close to pigment sources, should be investigated. Specific sites for future investigation should include the Mesolithic phases of Alderley Edge and the Triassic cupriferous sandstone outcrops of the Cheshire Basin and Shropshire. Also, there is much potential for sites in the Forest of Dean and on Exmoor.

DISSEMINATION

Research Aim 24: Improve access to past archaeological and historical research by creating an online information point listing published material relevant to the extractive industries.

a. The bibliography assembled for this assessment, and others, should be used as a basis for an online resource. Keep the resource up to date by adding new material regularly. Maintaining the site should be the responsibility of an non-governmental organisation (NGO) such as NAMHO.

Research Aim 25: Make detailed gazetteers of mine and quarrying sites with physical remains more available.

a. This could be done through county HERs, but there is value also in coordinated inventories through NAMHO, as this would allow more detailed data to be incorporated, and information with more informed peer-review, to be presented. These inventories, if independently produced, would also act as a repository of information for those counties/districts where incorporation into HER data bases proves slow or problematic. (*see* RA 04).

Research Aim 26: Encourage and enable more dissemination of research and synthesis, including traditional publishing methods and use of the World Wide Web.

a. Grey literature should more easily available using online technology. This aim is very much one of the broader aims of the British archaeology fraternity and inroads have been made through the Archaeological Data Service and OASIS, but it is necessary to ensure that mining and quarrying material is included.

b. Practical support and encouragement should be provided for independent researchers to publish the results of investigations.

c. More works of synthesis aimed at national overview of extractive industry topics should be published.

d. Authors on mining and quarrying topics should be encouraged to offer their work, or summaries thereof, to mainstream archaeological publications, such as national and county journals.

e. An introductory handbook on Mining and Quarrying archaeology should be commissioned and published. It should cover the range of remains, why they are important, how they can be studied, etc. No such handbook with national scope has ever been attempted (although in respect of quarries, Stanier 2000 covers some of this ground), and would be highly significant for students and academics (*see* RA 07), archaeological units (*see* RA 06) and independent researchers.

f. Resources and know-how should be provided to specialist and regional groups to enable previously published material to be made more generally available to non-members through the internet.

g. Mining companies, developers, and others who commission archaeological research assessments

and surveys as part of a planning condition, should be encouraged to allow access to the work on completion. During the compilation of the assessment, several instances of unnecessary secrecy came to the attention of the steering group, where valuable information is withheld from the research community by companies unwilling to release results.

16.3.3 Research aim by raw-material type

BULK MINERALS (stone, sand, gravel, limestone, quarries and stone mines)

Research Aim 27: Develop research approaches and techniques for the landscape investigation of the quarrying industry in England (*see* RA 14-18).

a. A comprehensive inventory of quarries, based mainly on early series large scale Ordnance Survey maps, is available through the British Geological Survey's Britpits database. For building stones, parts have been made public for about 70% of England as the Strategic Stone Study, supported by Historic England. This needs to be extended to the whole country and augmented both to increase the historic detail and widened to other bulk mineral uses. Most county HERs now have the basic information of location, name, extent and, in some cases, the minerals sought for quarries within their patch. However, HER entries on quarries are usually minimal when it comes to historical background for individual sites, accurate site descriptions or record of any archaeological evidence, except in the case of historically notable examples. More field recording and documentary research is required to make these HER entries more informative and more relevant. Information from other sources, such as the Strategic Stone Study, should feed into and augment these records.
b. Although field survey of quarries needs to be increased, these sites do present certain difficulties in terms of conventional archaeological survey methods. Vertical faces are difficult to survey graphically, while hollows are often filled with water and many quarries are covered by varying levels of vegetation. Health and safety is always a consideration. Remote survey techniques, including LiDAR but particularly historic aerial photo transcription, combined with 19th-century mapping would serve as a valuable means of understanding these places better.
c. Recording through ground photography is particularly useful at quarries, where other forms of recording are impractical, too expensive or non-productive. Photographic recording needs to take place particularly in quarries recently abandoned before equipment is removed and the landscape 'restored', or the pits become subject to flooding dumping (legal or otherwise), change of use and redevelopment. Working quarries should be subject to photo documentation, especially during periods of expansion or change. The limited photo-record that exist from the past is extremely useful to today's researchers as any record from the present will be to future researchers. Many post 1945 surface operations have been the subject of air photography commissioned by companies who should be encouraged to share these or deposit them for example at the National Stone Centre or county record offices. Subject to training and a code of conduct, the use of controlled micro-drones for surveying can be especially beneficial in rough or dangerous terrain such as mining and quarry landscapes.
d. Full archaeological assessments and surveys are needed where abandoned quarries of any date are to be re-open. In such cases the assessments need to be a planning condition.

Research Aim 28: Widen the reach of bulk-mineral research, to include a greater range of end products and their mineral sources, and address weaknesses in current knowledge around specific neglected materials, resource zones, end products, and mineral types.

a. Certain niche products such as stone implements (including flint) and abrasives, such as querns and millstones, are well served directly in archaeological terms, and building stone extraction is also, but more indirectly, well covered. A reasonable level of reporting for industrial uses is boosted by activity associated with lime-burning, but that of related stone extraction itself, is often quite incidental.
b. Aggregates production is extraordinarily poorly researched when viewed in the context of the scale of the sub-sector. The remarkable irony of the poor record of funding investigation of this industry's own past through the Aggregates Levy Sustainability Fund, is particularly poignant .
c. Those rock types which, in the past, have required relatively higher levels of capital investment, or served prestige clients, also appear to have attracted

more attention from historians and archaeologists. This leaves sandstone very much neglected, while sand and gravel production has seen scarcely any reporting. Archaeological investigation should be directed towards sandstone operations and further consideration needs to be given to the potential research opportunities within aspects of the sand and gravel industry.

d. There is considerable divergence in the historical and archaeological coverage of readily definable resource zones. For example, the granites of the Southwest and the limestones of the Yorkshire Dales are well described archaeologically, but others, such as the sandstones of the Pennines or the Midlands hard stone industries, have barely been touched.

Research Aim 29: The dichotomy between parish and other 'tied' quarries worked commercially need to be better understood, as do the functional and chronological relationships between small quarries worked for stone on particular projects and others where stone was used elsewhere.

a. Many quarries began life being authorised to serve the needs of a parish or town corporation, road building (e.g. turnpikes) and maintenance, or to supply specific farms, estates or building projects. Little has been reported (in practical or administrative terms) as to how such operations morphed over time into commercial enterprises serving much more extensive market.

b. Some quarries concentrated on bulk stone, while others made specific products such as millstones, troughs, gateposts, or lintels, etc. There are physical/archaeological differences between the two that need better characterisation.

Research Aim 30: Make greater use of documentary evidence, in conjunction with geological data and data derived from bulk mineral end use, as a part of the preparatory routine for fieldwork at quarry sites.

a. Although much may be gained from documentary evidence as a targeting tool for fieldwork, there is scope for a further, more systematic, approach, by combining other forms of data. Many of the bulk mineral end-products are especially prominent, e.g. visually, in the form of buildings, or economically, as in the case of feedstocks underpinning past industrial and agricultural processes, as well as the subsequent production of goods. Greater dividends might result from a more holistic stance by being coupled with petrographic data derived from stone buildings of 'known' vintage or by matching sources with consumer industries, as these are often better archived. Similarly, reference to the geological limits of deposits is clearly a basic refining tool for extractive sites.

Research Aim 31: Increase our knowledge of bulk mineral extraction in the period after 1540, by encouraging and resourcing, more archaeological investigations.

a. Site investigation, other than 'classical' archaeology, is typically very poor indeed for bulk mineral working and processing. Even for the medieval period, while well covered historically, it is under-represented in terms of field evidence. Historical accounts for subsequent periods are very uneven.

b. By far the most disadvantaged period for reported investigation of bulk mineral extractive activity and processing as a whole, is that following the Dissolution of the Monasteries, running up to the advent of industrialisation in Britain. Whereas original documentation, geological cross-referencing and evidence of use in buildings is generally potentially good, very little analysis and synthesis has been conducted systematically, in terms of quarry sites.

c. Archaeological research into bulk mineral activities post 1875/1900 is almost non-existent, especially for the years after 1918.

Research Aim 32: Increase our knowledge of technological transitions within the extractive processes of the quarrying industry, especially in the 20th century.

a. A sequence of important transitions occurred in the 20th century, which in archaeological terms are virtually uncharted. The major change was that from manual extraction to mechanisation (i.e. from hand getting/initial breaking/filling (loading)/tramming to face excavators) in some larger sites in the 1930s, but mainly post 1945; a move from tracked to trackless carriage usually followed. These developments brought with them a range of distinguishing features, frequently subtle (but readily identifiable by those who then worked in the industry), but still discernible in abandoned sites. Also, as far as is known, apart from society-preserved systems (usually not *in situ*) and museum

sites, no significant narrow gauge rail systems (once extensive) have been retained or recreated *in situ* within quarries.

b. A schedule of characteristics and exemplars of the manually and early mechanised sites should be prepared (in liaison with former workers) for identification purposes, to inform future research. A similar reference collection of extractive marks over time (wedge marks, plug and feather, drill types and distinctive marks, explosive marks and fractures, blast tunnels, and of explosives magazines) needs to be built up.

Research Aim 33: Improve our knowledge of the primary and secondary processing of bulk minerals.

a. Concerning aggregates, with the possible exception of a single, known project, it is doubtful if any sites showing examples of the three principal secondary processes (concrete mixing/concrete products/ coated roadstone) have ever been described archaeologically.

b. Relatively sophisticated stone products are seen in many buildings from at least the 11th century, if not earlier. In particular 'marble' (i.e. polished limestone) was widely used in shafts and ornamentation, but few accounts of processing works have been produced for pre-1800 operations. Little has been written on early polishing, sawing and turning techniques, particularly for stones other than Purbeck. Attempts should be made to locate and record in detail, sites processing building and ornamental stone (whether or not at quarries), especially for 'marble', prior to 1800, and particularly for stones other than Purbeck. The aim should be to discern changes of technique over time.

c. Special industrial sands, limestones (including dolomite and chalk) and in the past some other rock forming minerals, were subjected to a wide range of, often novel , milling and separation techniques. These are rarely if ever recorded, let alone preserved.

Research Aim 34: Develop improved methods of dating abandoned quarry workings.

a. Greater application of, and experimentation with, scientific and relative dating procedures should be utilised to improve our understanding of the sequence of activities, especially at sites likely to have been active over extremely long periods, during which there was usually little or no discernible change in the techniques applied. Good practice on this aspect needs to be gathered and shared (*see* RA 21-23)

Research Aim 35: Develop improved methods for establishing geological provenance by fingerprinting building stone and stone artefacts.

a. In the field of stone implements, for more than a century, there has been considerable collaboration between geologists and archaeologists on igneous and metamorphic rocks. In respect of limestones, palaeontology has been deployed rarely, but reasonably successfully, to suggest sources of stone supply, where otherwise uninformed assumptions have resulted in misidentification (e.g. most commonly in assigning polished stone to Purbeck Marble), or generalisation, notably in respect of assigning material to 'Bath Stone'. This situation could be much improved by borrowing technology used in hydro-carbon exploration, particularly the greater or routine application of micro-palaeontology. There is now potential for technological transfer between petrographic work (e.g. that undertaken in the last 20-30 years on heavy mineral anlaysis of sandstones in the Pennine Carboniferous Basin) carried out to establish sedimentological provenances, to its application in verifying types and possible sources of stone used in buildings. Although far from a precise tool, it would assist in narrowing down the supplies likely to have been involved, e.g. from the oft quoted generic 'Millstone Grit', to particular geological formations.

b. Consideration should be given to establishing a joint working group (e.g. via the English Stone Forum) between archaeologists, building conservators and geologists to produce a readily usable reference database of diagnostic indicators and techniques.

Research Aim: 36: Increase our knowledge of limestone extraction, lime burning and lime kilns of all periods in England.

a. Despite considerable archaeological research into lime-burning, there are still some gaps and controversies, particularly regarding terminology and variation of kiln styles over time and regionally. Surprisingly few accounts describe the related winning of limestone feed. By comparison little work has also been done on bottle-type, rotary and shaft kilns for lime or cement and even less on hydrating lime.

b. As a matter of good practice, lime-kiln research needs always to be tied back to the source of

stone, and the transition between kilns supplying local needs and wider commercial markets, could usefully be tracked further. Terminology, regional styles and chronological sequencing (from early transient methods displaying little trace, to industrial scale) needs to be established, gaps in knowledge highlighted. Attention needs to be directed to the identification of non-traditional, large scale, post-1824 kilns, particularly those reflecting experimental (up to 1950) or early transitional efforts between lime, hydraulic lime and various cements; work on kilns should ideally be referenced to other landscape, economic and social developments (*see* RA 74-75)

c. In the Peak District, early commercial lime burning of 17th to early 19th century date has been studied using detailed survey, but there is a need to carry out targeted excavations at kilns to learn more of their character.
d. Study is needed of the chronological and functional relationships between field kilns and extensive 18th and early 19th-century enclosure of upland commons. Approaches such as those by Johnson (2010) in the Yorkshire Dales, could usefully be applied to areas such as the Peak District and Mendip.
e. Archaeological research including survey and excavation needs to take place at quarries or mines known through documentation or other means to have early origins.

Research Aim 37: Improve our knowledge of prehistoric flint mining, particularly the distribution of prehistoric tools from individual flint mines but also the environmental and social contexts of flint mining in the Neolithic period.

a. A robust technique is urgently required which will enable the accurate sourcing of flint artefacts, beyond the reliance upon visual inspection. In addition, the only frequently used scientific technique - trace element analysis – has, so far, only been able to identify regional sources of flint and does not have the precision to identify specific flint mines. Consequently an accurate scientific technique is needed, which has the capacity to identify specific flint mines as the source of the raw material used for the production of an artefact.
b. Current understanding of the environmental context within which prehistoric flint mining took place is reliant upon outdated evidence, or samples taken from shaft fills which may produce a biased result that does not reflect the wider landscape setting. The literature records environmental sampling mostly of molluscan evidence from shaft fills (i.e. dark/semi-dark environments), which has led to the potentially erroneous conclusions that most mines were situated in wooded settings. Most pollen diagrams are distant from the extraction sites, so the results are extrapolated, and potentially misleading. A bespoke strategy is required using pollen, soil-micromorphology and related techniques at several flint mines, to sample well-contexted materials and create a robust documentation of a mine's environmental settings, from the Early to the Late Neolithic, to determine both chronological change but also regional variation.
c. More evidence is required on the location or form of settlement or temporary camp inhabited by the Neolithic miners, either amongst the earthworks or on their peripheries. The nature of extraction is destructive, thus where it has been extensive there is great potential for any form of settlement evidence to have been destroyed by the sequential advance of extractive activities if the temporary or permanent dwellings lie in the path of the mining. However, incomplete remains may still survive amongst the shafts and spoil dumps, and the periphery of the mined areas may also hold evidence for settlement. Consequently, future excavation strategies should not only focus upon the extraction loci, but also attempt to locate and characterise the mining settlements in the immediate vicinity of the mines.
d. Little is known about the flint miners, their point of origin and their life style. No modern skeletal analysis has been undertaken upon the human remains recovered from the flint mines. A modern analysis could go beyond the identification of age and gender of individuals to a better chronological context using Bayesian techniques. Strontium analysis could provide better evidence as to the point of origin for those bodies interred in the flint mines, and evidence of whether the miners and their dead were local or had travelled to the extraction site from further afield.

Research Aim 38: Investigate further the source of specific types of stone (non-flint) utilised in prehistory for toolmaking, including identifying quarry sites. This should also include characterisation of the extraction scale and processes involved at specific sites.

a. Despite the large amount of detailed research into the composition and general provenancing of non-flint stone tools, remarkably little research has succeeded in pinpointing specific sources to the

level that could be verified by fieldwork. In England, of about eighteen source areas, well recognised for over 60 years, only the, Langdale 'factory' has been scrutinised in detail.

b. While it is known that chert was widely used for tool making in the Peak District, from the Mesolithic to the Bronze Age, currently, no known quarry sites have been identified, although sometimes raw materials such as fine-textured black chert have a restricted range of occurrence.

c. The approximate sources of stone for a number of polished axes of the Neolithic have been identified in Cornwall near Camborne, Mounts Bay and others but no quarry sites are known. A targeted search for these sources is needed.

COAL

Research Aim 39: Improve our knowledge of the chronology, extractive techniques and social impact of the coal industry from the Roman period to the 20th century.

a. More archaeological research, focussed onto England's historic coal industry, needs to be encouraged. Although coal is one of the most important material elements in the history of the industrialisation of Britain, the coal industry lies outside the scope of many within the archaeological establishment, especially among the professional research community. The archaeological legacy of the coal industry of all periods needs to receive due consideration within the planning process, rather than being perceived as derelict industrial land, and should command a level of investigation and evaluation equal to other cultural remains before planning decisions, which may allow evidence to be destroyed, are taken. Without adequate research, there is a strong risk that the significance of coal-related field remains will be overlooked. All types of coal mining remains require investigation and conservation, not just those with iconic features such as headgear.

b. Many general and regional historical accounts of British coal mining have stressed the social and economic sides of the industry, with emphasis on mining over the last 100 years or so. From an archaeological perspective, in order to better interpret today's physical remains of coal mining, more research is needed on the techniques and equipment used during all periods.

c. Archaeology has barely begun to address the origins of the early coal industry in England. Although archaeologists are confident that coal was being burned in the Roman period, the source and extraction sites of this period, and those of the Dark Ages, are as yet unknown. Similarly, little is known of the archaeological footprint resulting from medieval coal mining. There is potential for all English coalfields (except Kent) to have been worked from the earliest period that this fuel was exploited and the evidence needs to be sought.

Research Aim 40: Increase our knowledge of the various technological and chronological differences between coal extraction methods over the entire temporal range of the industry in Britain.

a. The term 'bell pit' is used, often erroneously, to describe shallow pits workings for coal, and sometimes for iron and non-ferrous metal mining, based only on the morphology of surface evidence. However, it is certain that while bell pits do exist, underground methods varied depending on the nature and depth of the deposit. Very little archaeological exploration of shallow coal workings has been undertaken to establish the true underground nature, origins and techniques used in late- and post-medieval coal workings in England. As a first step in investigating these, sites with potential to answer questions about early production including outcrop workings and pit works, need to be identified. Following this, a methodology for investigating below ground evidence safely needs to be considered, perhaps in the context of modern opencast reworking (*see* RA 40g). There is also potential to identify regional variation in coal working techniques, based on such factors as geology, topography, date and tradition.

b. Comparison and analyses are necessary at 'early' coal workings, which were worked from multiple shafts, and those being opened and abandoned as work migrated following the seam, also later mining that was undertaken via a small number of deeper shafts and/or inclined drifts. Chronological understanding of these ways of working needs to be refined, both generally, from a regional perspective, and according to the scale and financing of specific collieries.

c. The discovery of several hundred artefacts from archaeologically dated contexts in the Lounge Opencast Site at Coleorton in Leicestershire provides an opportunity to establish a typological sequence of tools and structural timbers from Medieval and Post-Medieval coal mines in Britain. A study of this material would be the first based on the artefactual record, rather than the occasionally misleading evidence of early documents and illustrations, and would greatly increase the extent of our knowledge of coal mining in the period

concerned. Similar opportunities should be sought whenever new opencasts are undertaken (*see* RA 40g).

d. Surface features are often better preserved at mines on the peripheries of, or even beyond, the main coalfields (for example, on the Pennines and the North Yorkshire Moors), so a better understanding is needed of the scale and mode of extraction at such mines, in order to judge their relevance. Are these remains of relatively low importance because they represent merely small-scale extraction, or do they represent vital examples of early mining technology, which was universally employed before the extensive development of deeper mining techniques, particularly from the 18th to 19th century? Such an assessment will require a search for vestiges of early shallow mining remains in the main coalfields, as well as for other evidence of medieval and early post-medieval use of 'deep mining' techniques, such as long drifts and soughs, in places like the Pennine foothills.

e. More data is needed to explain better the underground techniques used in coal mines – pillar and stall, long-wall, bank work etc. Using the broad sense of the term, pillar and stall coal mining was extremely common at relatively shallow mines from at least medieval into the 19th century, but as yet we have very little understanding of the variations in character of this and the adoption of alternate extraction methods and the chronology of this change at individual collieries and regionally. With shallow mines there is potential for recovery of relevant archaeological data when old workings are intersected during modern operations (*see* RA 40g). However, in the case of deep mined coal, with so little documentary record of pre-19th-century coaling techniques, this aim could only be delivered through underground exploration, which currently is not possible, or examination of exposed sections during deeper opencast operations (*see also* RA 40g).

f. Deeper collieries that were abandoned in the 18th and 19th centuries, with more infrastructure than early shallow mines, were usually demolished at surface and their shafts capped, so little can be known of their appearance or extent. However, parts may sometimes survive as earthworks or below-ground remains. Investigation through a series of analytical techniques would help retrieve such surface detail. Geophysical, remote sensing and earthwork survey might reveal the sub-surface potential of such sites, while research excavations at selected or threatened sites would be very informative on a range of issues, including pumping, hoisting and ventilation technology, sources of power, coal washing and movement of materials.

g. More advantage needs to be taken of incidental discovery of underground coal working during modern episodes of opencasting or other forms of development, such as road building, where shallow to moderate depth underground workings are exposed. These occasions represent some of the only opportunities to examine underground coal working and to advance research; every opportunity needs to be taken to capitalise on them to the maximum extent. An awareness needs to be promoted within planning authorities and county HESs (*see* RA 01b) as to the importance of these opportunities, and ensure that an appropriate level of archaeological resources and expertise is written in to planning conditions as part of developer funding when these occasions arise. Cursory watching briefs by non-specialist archaeologists are inadequate.

h. Because so little has been published, there is a need for a review of all previous watching briefs, grey-literature reports and other archaeological recording within opencast sites. There is no certainty about gaps in knowledge and what types of feature are in need of recording in detail in the future. There is also a need for developers and archaeological contractors in their employ to be less secretive about the discovery and recording of underground remains and to make the results of this work more easily available. Recent planning reforms (2012) have increased the likelihood of new opencast coal pits being worked in the north of England in the near future. It is likely that many of these operations will cover less ground but will be deeper. It is a matter of some urgency that the historic environment sector engages in dialogue with the Coal Authority, local planners and companies such as UK Coal to discuss the issues of access to heritage assets, and to allow adequate time and resources to investigate properly and provide open publication of results.

i. There is a need for clarification, from historic sources, and by archaeological investigation, about the complex relationships between coal extraction and the working of other materials from the same mines, commonly including ganister, fire clay and iron ores (including pyrite/copperas).

Research Aim 41: Widen our understanding of coke making.

a. Coke production often took place near the pit head and field evidence has occasionally been recorded at such locations. More information is needed

about where this evidence survives the date and character of the activity need to be established. As yet there are no dates for the origins of coke making, although it is known that earliest historically documented production was in the 17th century using meilers (burning platforms), as used by wood and peat charcoal burners, a method for which subtle earthwork evidence could survive. By the late 18th century, beehive ovens, for which field evidence has also been recorded, were the emergent technology but as with all technological change, old methods may have continued in the face of newer ways, driven by either economy or local tradition. Fieldwork, including excavation could help answer such uncertainties. From the 18th to 20th century, banks of coking ovens survive and a better record of these remains is needed.

Research Aim 42: Expand our knowledge of the mining and processing of oil shale and those coal deposits used for oil extraction.

a. The mining of cannel coal made a significant contribution to the production of oil based products in the last half of the 19th century. Oil shale mining and processing had a limited application in England due to its high sulphur content but there were ill advised attempts to work those deposits during the First World War, through to the 1920s. Our knowledge of the industries is limited and they are seriously under-represent in the Historic Environment Record, such that surviving evidence is at danger of being lost through neglect and/or development.
b. A full survey of oil shale and oil-bearing coal extraction sites, along with the associated processing, is required. The results to be incorporated in the Historic Environment Record and all opportunities taken to carry out detailed archaeological and historical investigation of those sites.

IRON

Research Aim 43: Address the lack of archaeological data for prehistoric, Romano-British and Dark Age iron mining in England.

a. Research is needed to address the complete absence of archaeological examination and dating in the Forest of Dean, of what probably are the largest single examples of still visible 'ancient' metal mine workings in the UK. The abundance of charcoal within mining works and smelting sites suggests that absolute dating of excavated undisturbed deposits should not be a problem. There is also good evidence for firesetting using coal in some mines, but, as yet, radiocarbon dating on the kindling used has not been attempted. The reasons why Roman iron working has so far proved to be late in this area need to be investigated. A study of these mines may well also prove valuable for medieval studies.
b. The Northampton – Lincolnshire orefield is probably one of the most important iron producing regions of Roman Britain. Much of this ore was quite low-grade, though these outcrops would have been relatively easy to work. Establishing the area of original workings and the extent of early production, together with how influential iron production was on the siting and growth of civilian settlements, forts and the road network all need to be researched.

Research Aim 44: Increase our knowledge of iron extraction in England during the medieval, post-medieval and modern periods, using the full range of investigative techniques available.

a. As with earlier periods, research effort has been disproportionately in favour of iron smelting and to some extent the study of artifacts, leaving a serious void in research aimed at identifying and dating the sources of ore. Landscape investigation and survey has tended to be at desktop level, with limited fieldwork for regional coverage or very localised when examining sites in greater detail. For example, targeted follow-up research in the Forest of Dean, to complement the excellent work of Hoyle et al. (2007), could include large-scale survey, excavation, scientific analysis remote sensing and documentary studies to help establish a firmer basis for interpretation and dating in this region.
b. For other known iron producing areas an inventory of iron extraction sites would serve as a basis for more detailed work.

Research Aim 45: Improve our knowledge on the underground archaeology of the modern ironstone industry in the English Midlands.

a. The underground archaeology of the modern, late 19th to 20th century, ironstone industry is little understood. This is particularly so in respect of the Mesozoic ironstones of the Midland counties in England. Although much of the ironstone working along the Jurassic Scarp was largely carried out by opencast methods, there were significant underground mines in Lincolnshire and Leicestershire, some of which remain accessible.
b. Where underground workings for Mesozoic

ironstones are accessible, as in the Scunthorpe area of Lincolnshire, a full programme of recording should be instigated.

Research Aim 46: Use archaeological investigation to better record the evidence for iron and ironstone extraction in the lesser known iron-ore fields, along with the associated infrastructure.

a. Research and recording of iron extraction sites carried out to date has focused on the better known ore fields, areas such as Furness, now part of Cumbria. Ironstone workings in Northumberland - the extensive ironstone workings in Redesdale and the North Tyne area - are totally unrecorded. A similar position exists for the Namurian ironstone deposits in Nidderdale, Yorkshire, and sources of ore for the many recorded furnaces of the Weald in Sussex, Surry and Kent, have not been researched as thoroughly as the smelting. Despite a number of significant historical references and interest in iron smelting sites in that area, there has been no detailed investigation of extraction sites. A comprehensive study to record, map and interpret the ironstone workings in these and other similar areas is long overdue.

Research Aim 47: Investigate the processing techniques used to enhance iron content of ores as mined, in all periods.

a. Relatively little processing was carried out on iron ores/ironstone prior to shipment for smelting and what techniques were used are relatively understudied in comparison with other metal mining sectors.
b. Initiate a research programme to examine the processing of iron ores/ironstone. Record and evaluate the archaeology of techniques such as the crushing and calcining of iron ores.

Research Aim 48: Take more advantage to record the iron workings when coal measure ironstone deposits are stripped away during opencast coal working.

a. Coal Measures ironstone was the prominent source of supply for the British iron industry prior to the mid-19th century yet its history and archaeology is relatively understudied.
b. Iron is among the most common minerals and sufficient could be mined to supply a small bloomery in most areas of England, yet little is known about the extraction processes outside the major iron-ore fields. Identification and investigation of the numerous minor sources of iron ore across England is needed, particularly where there is field evidence for smelting sites but no known evidence for the source which supplied them. In addition to recording the smelting sites, where the resources were of a marginal nature and not worked beyond the post-medieval period, the emphasis should be on recording the ore sources.

CLAY

Research Aim 49: Understand better the links between English clay sources, the manufacture of ceramic products and the infrastructure which linked them.

a. The ephemeral nature and potential instability and flooding of *in-situ* evidence for many aspects of clay working has led to under-recording of that evidence with greater effort being given to the archaeology of clay processing in the form of pottery kilns and brick making. In future investigations, greater emphasis is required on the sources of the raw material, and the techniques used to extract and transport it to the ceramic production sites. Analysis of the ceramic evidence, linking the product to source materials, has made significant advances and might be used more frequently, and as part of comprehensive studies, to identify clay working sites across England particularly for the Medieval and earlier periods.

Research Aim 50: Use archaeological investigation to build on our knowledge of specialist (china and ball) clay industries in SW England

a. The china clay industry of Cornwall and SW Devon, has its origins in the mid-18th century and is still active. Because many of the extraction sites remain operational, the nature of the process has meant that expansion of the works over time has effaced all but a very small percentage of the earlier evidence of extractive activity; what is seen today is, essentially, only the last phase of work. Abandoned china clay pits are usually flooded and any evidence surviving above the water level is often overgrown. However, in these surviving areas, evidence of hauling, pumping, tramming, dumping and water supply infrastructure often remain while that for settling and drying the product sometimes survives in the form of

drags, settling tanks, kilns and other infrastructure. The landscape around active china clay works can change rapidly so, where surviving, this evidence is under constant threat from renewed episodes of extraction and dumping. Few such remains are scheduled and their recording, and in some cases, conservation should be seen as a priority.

b. The use of ball clay, or potter's clay, found in Devon and Dorset on an industrial scale, occurred probably from the 17th century, though there is good reason to believe that these clays were exploited as early as the Roman period. The major landscape evidence of ball clay extraction is the clay pits themselves and the evidence of dumping, but surface infrastructure is known to survive in places including transport systems such as the Stover Canal in Devon. More needs to be known about the early development of the industry; and the places where clay digging first took place.

Research Aim 51: Increase our knowledge of fuller's earth production in England, from the Roman period to the 20th century.

a. Fuller's Earth is believed to have been used in England since Roman times. It is found at a limited number of locations, dictated by its somewhat unusual geology, and was exploited well into the later 20th century. Evidence, therefore, is going to be equally limited, particularly for the earlier activity. Although some historical research has been completed (for the Coombe Down workings near Bath for example), archaeological investigation has not yet been undertaken at any site in England. Most claims that fuller's earth mining has early origins have been passed down anecdotally, and substantiating these and establishing the true origins of surviving fullers earth mines, needs to form an initial focus for research. Recording and interpretation of surface evidence from all periods is also required urgently.

NON-FERROUS METALS

SILVER, LEAD AND ZINC

Research Aim 52: Improve our knowledge of early (prehistoric to Dark Age) lead extraction and smelting.

a. The ability of Bronze Age people to smelt copper would imply that the smelting of lead was also possible, although the extent to which lead was used in prehistory is open to question and lead artefacts are rare. However, examination of excavation reports for the presence of smelting residues may yield clues about the location of lead working sites in the Bronze and Iron Ages.

b. The only excavations undertaken on the Mendip Hills in Somerset, suggest the possible survival of *in situ* mining features, and possibly smelting hearths dating from the early Roman period, and perhaps even pre-Roman remains dating from the 1st millennium BC. Potentially, one of the most important early Roman lead mining areas within Britain, this area is worthy of detailed survey, soil augering, geophysics and focused excavations. Given the known silver content, the Mendip Hills is also an area to look for evidence of silver extraction (cupellation) from these ores.

c. Evidence for Roman lead mining in other orefields in England is usually confined to isolated finds of inscribed Roman-period pigs (ingots), while contemporary evidence of extractive activity has proved elusive. With vein extraction, the problem is often the effacement of Roman workings by later, deeper episodes, or the reworking of wastes, and the presence of dumped waste, which may overlie earlier mining evidence. A related problem is that medieval and earlier miners may well have employed similar techniques to their Roman period predecessors, making the fine-tuning of chronology difficult without detailed excavation.

d. The Miner-Farmer Project in the Northern Pennines has identified 'early' mining but precise dating is problematic. A research strategy is needed whereby all relevant regions are targeted, to search for evidence of Roman and medieval mining, particularly aimed at identifying places where post-medieval evidence is believed either absent or minimised and underlying episodes stand more chance of survival. As well as addressing the Roman problem, the results may well also be equally valuable at understanding medieval mining, which is another under-researched topic for most regions (*see* RA 54).

e. Excavation and dating of lead boles should be used as an indirect means of identifying Romano-British and medieval lead mining. There are many bole-smelting sites known in the Pennines and Peak District; a few are relatively close to mines, but many are set at a distance near fuel sources. Without excavation these sites are often recognisable from little more that low piles of slag and other associated debris. In the Yorkshire Dales a series of radiocarbon dates suggest medieval, rather than earlier, smelting and we know from documentation that here, and in the Peak District, the use of boles continued into the

16th century. Carefully controlled archaeological excavations, with detailed scientific analyses of structures and deposits to maximise return, are needed to refine the explanation of these sites.

f. It needs to be established if a similar dating range applies across regions, or can different dating trajectories be identified? It may be that sites set away from the mines are a medieval, or sometimes later, phenomenon resulting from fuel becoming scarcer. In which case, evidence for smelting in the Roman period should be looked for closer to the mines or in settlement contexts; small scale lead processing in a domestic context is known in the Peak District, for example, but large-scale, more sustained, activity should be sought and identified.
g. Liason with European colleagues to build a picture of Roman trade in metals across the Roman Empire could provide useful lines of enquiry, especially if combined with scientific provenancing techniques.
h. From the historical record it is known that lead was being mined and used in the pre-Norman period and it has been argued that many customary mining laws date from the Anglo-Saxon period. Further research is needed to identify possible pre-Conquest mining and smelting. Radiocarbon dating from bole sites may help in this search.
i. An expansion of the use of palaeoecological techniques and wider circulation of the existing data, may help to identify early metal mining and smelting areas but the degree to which such assessment can be tied to particular periods, needs further research.

Research Aim 53: Assess the importance of regional variation in the silver content of lead ores and how this affects the mining traditions of various mining districts from the medieval period to the 19th century.

a. Some regions, such as Devon and Mendip, are recognised as producing ore that contains silver; others, such as the Peak District, were known to be normally silver-poor in the post-medieval period. In the Peak orefields, mineralogical analyses of samples from hillocks, (waste heaps) at sites known or thought to be early, are needed to determine the silver content. Alternatively, it may be that larger vein sources near surface (where there was more oxidisation of the ores), that were largely worked out at early dates, had a better percentage of silver. A better understanding of this will significantly enhance knowledge of Roman, and other, early mining across the different regions of Britain.
b. The mining of silver-bearing ores differs little, if at all, from that of the base metals that hosted them, but the treatment of the ore, once mined, differed significantly. The identification and recording of sites where silver-bearing smelting residues (slags) were re-worked is essential, as is the identification and investigation of silver refining sites. Action is required to identify and investigate the sources of the ores refined at sites such as Pentrehelig on the Shropshire / Montgomeryshire border.
c. Prior to the centralising of minting in London and Canterbury, from the 13th century onwards, the sources of silver used in English coins have not been comprehensively tested. Some regional and burgh mints may have drawn on local supplies, and an analysis using techniques such as lead isotope analysis, for coins identified with those mints would assist in understanding the flow of silver into the English currency, and identify any use of local sources. (see RA 21f).
d. In the 18th-19th centuries, silver continued to be won from mines also capable of producing lead. Although the retrieval of silver at specific mines was often documented by that time, the processes used at surface may not be immediately evident. Where mines produced ores capable of producing lead, silver and zinc, archaeological recording and sampling techniques need to be developed to identify the presence of these three elements within the dressing and smelting processes at surface.

Research Aim 54: Broaden our understanding of medieval lead extraction and smelting in England.

a. It is often stated, that in the Yorkshire Dales, monastic houses were the engines of medieval lead mining and smelting. A research programme, including excavation, to investigate monastic activity in this and other orefields is needed to qualify such historical assumptions (see also RA 19).
b. There is a reasonable body of information describing Roman lead pigs, but a search of known later pigs, retrieved from archaeological contexts at the end-user destination, may, through stable isotope signatures (see RA 21f), yield further information, such as the provenance of the ore
c. In the Peak District, recent underground research has identified several mines that are likely to be medieval. Evaluations are needed in other English lead orefields to search for comparable evidence. Traditionally mine explorers have concentrated on larger 18th- and 19th-century workings, neglecting potentially earlier workings because they are less extensive. This imbalance needs redressing.
d. Excavation and dating of lead boles should be used as a means of identifying locations of medieval lead

mining (*see* RA 19).

e. Archaeological methods and strategies should be developed, specifically designed to identify medieval lead mining operations. Unchanging traditions among miners have left very broad chronologies for some of the mining techniques used. More work is needed to learn to recognise chronological differences in field remains and artefacts associated with mining. The investigation of medieval lead workings needs to be informed by historical documentation, and collaborative projects are more likely to bear fruit (*see* RA 08).

Research Aim 55: Improve understanding of post-medieval lead mining and ore dressing techniques with particular reference to the chronology of technological advance and its overlap with tradition coupled with social impact.

a. Identifiable underground mining was taking place in the medieval period, but differentiating between medieval and post-medieval remains is difficult. A typology of mining techniques needs to be researched, and applied, across all the lead mining orefields (*see* RA 54).

b. At post-medieval lead mines a wide range of aids to deep mining were employed to combat flooding and to raise ore to surface. Nineteenth-century mine complexes frequently have visible remains of structures, which are recognised and understood, or they are known from paintings, plans and, latterly, photographs. However, very little is known about how larger 17th- and 18th-century lead mines appeared at surface. Some lead mines have extensive historic archives that provide crucial information, but there are still some types of structures of which nothing is known. Better archaeological information is needed on the practices used for winding, pumping and the movement of materials at surface.

c. Ultimately, the questions of new technology versus tradition, and the likely chronological overlap, will lie in analysis of documentary sources for individual mines; but archaeological evaluation and excavation (*see* RA 19) will be a useful way of confirming chronology at such sites, and illuminating under-documented developments.

d. A better appreciation of the different scales of lead working is needed, comparing and contrasting large, well-financed mines, employing full-time miners, with small, part-time miner-farmer operations. In the past, the contribution of miner-farmers to the mining industry may have been under-valued by researchers. Similarly, the activities of people who earned a meagre living from reworking waste heaps have not been investigated archaeologically.

e. A better understanding of lead hushing is needed**.** It used to be thought that hushes were primarily an ancient method of working, but it is now known that some at least date to as late as the 19th century. Targeted survey and evaluation excavations should be undertaken to gain a better grasp of the techniques used and a more accurate date range.

f. Archaeological excavation is needed to appreciate better the techniques and chronology of ore dressing at lead mines. While 19th-century mechanised dressing floors at larger mines are relatively well documented, but we know very little about dressing arrangements at earlier mines and smaller mines generally. Targeted archaeological excavations are needed to uncover the details and, where possible, the facts about these processes. Similarly, the extent to which larger 19th-century mines used 'new' developments in ore dressing, needs to be explored, and to what extent older methods prevailed and for what reasons.

g. A corpus of surveys of lead smelting mill sites throughout England is needed. The technology is reasonably well known but the practice of lead smelting is not as well researched. Archaeologically derived data could throw much new light on this topic.

h. Prior to the introduction of new processes from the late 16th century onwards, the smelting of lead ores was often, though not universally (i.e. in the Yorkshire Dales but not in the Peak District), carried out close to, or intimately linked to, the mining sites but differences need to be better understood. While the wind-blown 'bole' hearth was commonly used, there were other different techniques in use, which are not fully recognised. Archaeological and archaeometallurgical investigations are required to identify these techniques and reasons why they were used.

Research Aim 56: Improve our knowledge of the mining and production of Smithsonite (calamine).

a. Following its discovery in the 16th century, the extraction of smithsonite was restricted to only a handful of sites in England, including Mendip, Derbyshire and Yorkshire, yet its exploitation as a metallic element was crucial to the development of the brass industry. Some historical accounts have been attempted, and calamine mines have benefitted from modest underground explorations, but little is known of the physical remains or extent of this

industry. Field and documentary research is needed to identify the locations of smithsonite extraction, and then define the character of the remains above and below ground. This knowledge will help with the recognition of undocumented smithsonite extraction elsewhere.

Research aim 57: Establish a range of archaeological techniques to enable recognition of zinc extraction at mines known primarily for their output of lead and/or silver.

a. Zinc sulphide, or blende, was a by-product of lead mines or, later, a sole product of mines which formerly produced lead and/or silver. It is likely that underground techniques for zinc extraction did not differ from those of other ores, however, surface activities certainly could, especially dressing. The techniques used uniquely for zinc dressing and the types of evidence we might expect such as specific machinery or residues, need to be identified. Although useful at silver/lead mines where zinc production is documented, such archaeological techniques will be essential at sites where there is no historical record of zinc production and interpretation of remains relies wholly on archaeology (*see also* RA 66).

TIN

Research Aim 58: Address the lack of archaeological data for prehistoric, Romano-British and Dark Age tin working in Southwest England.

a. Evidence has been retrieved from Cornish tinworks that implies prehistoric tin extraction was occurring in the 2nd millennium BC and classical period writers referred to the export of tin from Southwest British sources. However, most of the archaeological 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, and recent maritime finds of ingots. Evidence of early tin working retrieved from archaeological excavation is still rare. Nothing is known of the precise locations where alluvial tin extraction and smelting was taking place in the Bronze Age through to the early-medieval period.
b. Palaeo-environmental studies would be helpful to try and elucidate the alluvial history of Southwest rivers affected by tinworking and also to try and detect palaeo-tinworking sediments which can be dated and analysed for metal concentrations. Air pollution from smelting is detectable from peat cores and provided approximate dates for metallurgical activity but more work is needed to refine these techniques. (see RA 21).
c. More evidence is needed to test the assumption that tin was regularly being traded to the continent and the Middle-East, as was alluded to by classical writers, and if so, to establish when this trading started.

Research Aim 59: Address the shortfall in our archaeological knowledge and chronological detail for medieval and early-modern tin working, dressing and smelting.

a. Alluvial streamworks probably represent the earliest form of tin extractive activity in England, and the techniques may have first been used in a simplified form in the prehistoric period, yet streamworking was still in occasional use in the 19th century AD. None of the hundreds of streamworks surviving as archaeological remains in Devon and Cornwall have been reliably dated. Knowledge of streamworking techniques is based almost exclusively on interpretation of historical descriptions, from the 17th century or later, augmented by some recent earthwork surveys and a small amount of excavation. This has been of some use in providing an approximate understanding of how streamworks functioned but each tinwork has a unique layout and there is still much work to be done to establish how water was utilised and waste materials disposed of.
b. Tin openworks, where relatively shallow lodes were exploited, were common in Devon and Cornwall from the medieval period onwards but, unlike streamworks, the limited number of contemporary accounts (e.g. Anon 1671) of working methods only add to the enigma. The openworks have been likened to the lead hushes of Yorkshire and Wales in both appearance and extractive techniques, including the use of stored water, but this is probably far too simplistic. Many tin openworks may have started life as streamworks, where shallow, more weathered deposit were worked before the underlying lodes were exploited. The precise purpose of the water supplies is still not certain but explanations range from exposing the deposits through to washing and concentrating ores. Given the tight regulations enforced by the Stannaries, the disposal of waste and overburden from these workings, is another issue for which we have only a vague grasp. Although theories abound regarding openworks, archaeological

evidence has yet to confirm any of them.

c. Outcrop workings, sometimes known as lodeback pits, were probably an early form of shaft, where vertical access to the upper sections of tin lode outcrops could be achieved. It is likely that methods of deeper shaft mining represent a developed version of this technique. The origins, and period of usage, for the technique of outcrop workings is still a matter of informed guesswork, and although there are hints within contemporary accounts as to the introduction of deeper mines as pumping and hauling methods improved, the chronology or economic and technological progression of the transition is unknown.
d. Although tin stamping and dressing mills of the late medieval and post-medieval periods are comparatively well studied, some questions remain unanswered, including the date for the introduction of this technology. Accounts of tin dressing and smelting techniques are still heavily biased by interpretations of the historical record, which does not commence until the 16th century, rather than archaeological evidence. For the medieval and earlier period virtually nothing is known. Also unknown is what preceded the use of tin mills: how and where was tin ore prepared for smelting prior to the availability of stamping mills; is our current assumption correct that this technology was introduced through necessity when the less pure lode ores began to be exploited?
e. The practice of burning, or calcining, tin oxide to remove impurities was known to Agricola in the 16th century, and early-design tin kilns, which were forerunners of the reverberatory calciner, were described in Southwest Britain by 1671(Anon 1671). However, no structural or archaeological evidence of a calciner of a date earlier than the late 18th century has been recorded.
f. Smelting of all periods is among the least archaeologically researched aspects of the tin industry. Although many surviving blowing houses provide ample field evidence of *c.*14th- to *c.*18th -century blast-furnace smelting, only one fairly late example has been excavated and the results are still awaited. Historical inference suggests that, prior to the introduction of this technology, two smelting operations were required – one near the site of extraction followed by a second within the precinct of a stannary town. Archaeological evidence for either of these earlier smelting operations is yet to be retrieved. (*nb smelting which occurred away from the site of extraction, for all metals, is not included in the brief of this agenda.*)

Research Aim 60: Expand our knowledge of later tin mining, including social and landscape impact and the impact of technology (water, steam, electricity) and transport. Also explore themes in common with copper where the two are mined alongside.

a. In Cornwall, the mining landscape is dominated by remains from the 18th to 20th century, including many ruined structures, earthworks and surface evidence for underground mining; but also dressing, disposal of waste, recovery of slimes, movement of materials and social infrastructure. Some of the evidence is associated with tin, some with copper and some with both. Much basic-scale mapping and field recording has been undertaken, along with some quite detailed work, in association with various projects, culminating in the compilation of a comprehensive database associated with Cornwall County Council's GIS. However, there is still room for more fieldwork at larger scales, as many of Cornwall's mines remain to be surveyed or investigated in detail (*see* RA 14 & 15).
b. For the Devon tin mines of this period, although fewer in number and smaller in scale, a basic inventory based on field recording is yet to be compiled, and the Devon/Dartmoor HER is far from complete. Rectifying this should be seen as a priority, especially in areas outside the protection of the Dartmoor National Park. The Devon tin industry is often perceived as less significant than that of Cornwall, but as a more marginal area of the orefield, it holds crucial archaeological and historical evidence about smaller-scale and marginal tin mining in the 18th to 20th centuries
c. Research excavations focussed at later period tin mines have been few, yet many of the questions that might be asked about the development and adoption of technology, sources of power, scale of working, dressing techniques and impact on the environment, could be informed by targeted excavation, as suggested for other metals (*see* RA19), especially where documentation is lacking, or where historical interpretations need to be challenged.
d. A firm line of distinction needs to be established between the surface processes used at copper and tin mines. Theoretically, these issues can be explained through technical writings but the reality is that interpretation of field evidence at individual site level is less straightforward where structures and apparatus have been removed, but could be illuminated through excavation and sampling. Similarly, the extent to which the technical writings reflect what was actually practiced by miners, who may sometimes have adopted more pragmatic compromises, needs to be tested.

COPPER

Research Aim 61: Increase our knowledge of early copper mining in England, from the Bronze age to the Romano British period.

a. Apart from the work at Wheal Coates (Cornwall), no prospective archaeological excavation of an early copper mining or smelting site has ever been attempted in Southwest England, although it one of the most copper-rich orefields in the United Kingdom. There is a need for a systematic survey to look for prehistoric copper mining in Cornwall and more methodical provenance analysis of copper metallurgy and artefacts, so as to get a better idea of the origins of copper ores used in ancient artefacts.
b. Further focussed research excavations at Alderley Edge (Cheshire) and Ecton (Staffordshire) need to be undertaken, aimed at answering specific questions about prehistoric mining. Previous work at these two sites has comprised only small evaluation excavations. To properly understand these sites, full-scale excavation is needed. The most obvious target is at The Lumb at Ecton, given the relative lack of later reworking, building upon evaluation work already undertaken. Very little has been archaeologically excavated at Alderley Edge and, given the damage here caused by natural and human erosion, the opportunity should now be taken for further characterisation. These mines may have been worked for pigment rather than metal, even in the Bronze Age. Possible roasting hearths at Engine Vein still need to be investigated.
c. It has long been suspected that there may have been prehistoric copper extraction in Cumbria, but evidence for this has proved elusive to date. A targeted, systematic fieldwork strategy is needed to search for evidence.

Research Aim 62: Use archaeological evidence to test the historically-derived narrative for, and expand our knowledge of, 16th- and 17th-century working of copper in Cumbria and Cornwall by German miners.

a. German miners' working of Cumbrian copper resources is well known through historical sources, reported in detail several decades ago (Donald 1955). But there is a need, with the aid of archaeological investigation, to validate the historical accounts, review the interpretation and narrative which resulted, and establish the true impact of imported German expertise on the development of British mining. While valuable work on underground Cumbrian mines of this period is on-going there is also a need to understand surface structures and dressing techniques better, using current archaeological methods of investigation and interpretation. It has sometimes been claimed that the Germans introduced continental mining methods to Britain, the character of which is well illustrated by Agricola and others, but the question remains as to whether any significant documentary or archaeological evidence exists to support this. It may be that 'continental' mining methods had already been adopted in England or had evolved independent of outside influence. Conversely, the presence of German miners in Cumbria may have had very little effect on miners in other regions of Britain who continued using traditional local methods.
b. The available archaeological evidence for copper mining prior to the end of the 17th century is limited to specific areas, including parts of Cumbria, Alderley Edge and Ecton; greater research effort needs to be directed at copper mining in other parts of England, particularly the south-western counties, where the limited evidence for medieval and earlier smelting should be followed up with detailed investigation of the surface and underground evidence.

Research Aim 63: Broaden existing knowledge of copper mining and dressing during the 18th and 19th centuries and develop a national archaeological research programme that brings together regional and local studies.

a. Archaeologically, copper mining is the least studied of the main non-ferrous metals. This may be because the industry was on a small, or locally concentrated, scale in some regions, but an overall context for the archaeological study of copper mining needs to be developed for the British Isles.
b. Copper, like lead, is dispersed through several regions and no coherent national archaeological overview, which might bring together data from different mining districts, has been attempted. Although a significant proportion of the key sites have been surveyed, there are others where this is awaited. With the notable exception of Ecton, there is still much to be surveyed in detail underground.
c. Although there are many copper mines in Southwest England, the development of underground tin extraction in the 19th to 20th century, using new or modified infrastructure, has tended to dominate the context and agenda of mine research in this part of Britain. A review of the archaeology of

18th- and 19th-century mining remains needs to be compiled and made available. In particular, a firm line of distinction needs to be drawn between the surface processes used for copper and tin at mixed mines. The less dispersed character of copper ores is believed traditionally to be the reason why copper mining was a more labour intensive industry, relying on hand-crushing and picking techniques. However, the recording, excavation, sampling and analysis of copper dressing sites has barely begun, and it is necessary to test some of the assumptions made about these processes and the balance between manual and mechanised techniques, the chronology of change and social impact.

d. At Ecton in Staffordshire, which has recently been surveyed in detail (Barnatt 2013), there is a need for targeted excavations at surface and underground to understand further specific points of interpretation (*see* RA 19 & 61a). There is a need for similar investigations in Cumbria, at Copper Mines Valley, Coniston and around Keswick in particular,
e. Further investigation of copper recovery, particularly acid leaching and cementation, is needed to improve our knowledge of this aspect of ore refinement.

GOLD

Research Aim 64: Broaden our knowledge of gold extraction in England from the prehistoric period to the 19th century AD.

a. Gold was probably the first metal to be exploited in Britain, perhaps by the late 3rd millennium BC. Although gold artefacts are among the most studied forms of material culture from the Neolithic and later periods, the ore sources are rarely a focus for research, although it is known that placer deposits and native gold existed in the British Isles and were exploited from earliest times. Trace element composition analysis and stable isotope ratios directed at gold artefacts of all periods could help identify the extent and location of past gold extraction in England (*see* RA 21f). Some work has already been undertaken on Bronze Age gold artifacts in Ireland, with a view to identifying sources, but very little has being attempted in England, Scotland or Wales. Because of the purity of alluvial gold (93% Au), trace element studies and studies of stable isotope ratios may prove effective. Potential gold stream sampling projects might include: West Cornwall and Exmoor.
b. Attempts to exploit gold in Scotland, using techniques akin to alluvial tin streaming, are known, and undated field evidence has been recorded at a limited number of sites. None have yet been recorded in England and a search at potentially fruitful locations could confirm the existence of sites here.
c. Nineteenth-century gold extraction in England enjoyed very limited success, and occurred predominantly in the Southwest. Typically, gold was not the primary ore to be exploited, but it often occurred alongside copper and tin. The most likely archaeological evidence for gold at these sites would be among the dressing areas, including possibly the remains of ore residues from specialist equipment such as Berdan and Britten pans. Mines where the extraction of gold is documented require closer scrutiny to search for such evidence.

MINOR METALS AND MINERALS

Research Aim 65: Increase our knowledge of minor metal and mineral extraction through a combination of historical and archaeological research.

a. In England, minor metals and minerals that have been exploited in the past include alum, antimony, arsenic, bismuth, cobalt, jet, manganese and tungsten. Although the outputs of some of these products have been worthwhile, their occurrence nationally is extremely limited, and often confined to a few small mines, which sprang up to exploit small concentrations of the minerals. Some sites are well known and a little historical research has been undertaken, but knowledge of the material remains is limited by a lack of archaeological research directed specifically at the exploitation of these metals.
b. A useful starting point would be a basic inventory of surviving sites and locations where these metals are known to have been exploited (*see* RA 04), established through the documentary record and mapping.
c. Historical research examining technical writings could help determine details of processes used, and help identify field evidence.
d. Fieldwork, including sampling of residues, would confirm precise locations of minor metals and miscellaneous mineral production.

Research Aim 66: Find out more about the development and use of advanced ore preparation processes.

a. The archaeology, and history, of modern (i.e. post-1900) non-ferrous ore preparation is seriously under researched. A programme of archaeological investigation into the development of advanced ore dressing processes, including gravity separation and flotation, is needed. Such an investigation should take into account the early work on flotation carried

out in Wales, and its development as a commercial reality in New South Wales and America as well as its application in England. Such preparation methods are particularly relevant for the topics of minor metal separation at mines worked commercially for other metals such as zinc/lead and tin/tungsten.

Research Aim 67: Broaden our knowledge of the alum and copperas industries through a combination of historical and archaeological investigation.

a. Much research aimed at the alum industry in England has focussed on coastal alum works, particularly in the Northeast. A comparative study of the less well-known inland alum sources is required.
b. That which is already known of the English alum industry, needs to be considered in its wider British/European context and there is a need to examine the industry from an economic and technological perspective.
c. Regarding copperas, there is a particular need for more work to be done on the coalfield copperas, which has so far attracted little research energy.

Research Aim 68: Improve our knowledge the jet industry in Cleveland and Northeast Yorkshire through a combination of historical and archaeological investigation.

a. The archaeology of the mining of jet is relatively understudied. A large number of extraction sites have been identified, particularly as a result of rapid coastal zone survey, but no investigations have been carried out to determine their dating. There is also a lack of evidence for the working, post-extraction processing of jet, other than the known Roman sites and the late-19th-century industry in Whitby. Jet artefacts from the early medieval period have been identified as a result of archaeological investigation and the presence of jet deposits was documented in the post-medieval period, yet jet workshop sites of those periods have not been identified.
b. Where jet extraction sites are known, archaeological investigation is required to identify the date and scale of those operations. Attention should be given to recording and investigating all evidence for jet processing to determine where and on what scale the industry operated in the medieval and post medieval periods.

GANGUE MINERALS AND PIGMENTS

Research Aim 69: Improve our knowledge of gangue mineral extraction, where these minerals were worked as a secondary economic mineral.

a. Gangue minerals, initially considered to be waste when occurring alongside minerals of greater economic value, often developed an economic value of their own and were exploited underground from the same mine source, either by continued primary extraction or through re-working of spoil dumps. Elsewhere, the extractive activity may have occurred contemporaneously with that of the principal ore. In all cases there should be distinguishing archaeological evidence. The archaeology of gangue recovery has never been examined so it would be easy to misinterpret the remains of a mine historically associated with lead for example, whereas the surface and underground remains may have been radically changed by later fluorite production. Methodologies need to be developed to help recognise the diagnostic evidence for such activity.
b. Gangue minerals are often seen as a side issue, incidental to base metal mining; yet their exploitation was a major extractive industry in its own right. Before the features are lost, more recording is required of gangue minerals' mining and processing, much of which is ongoing, or only recently abandoned. Conversely, a search for archaeological evidence for early gangue mining is needed, as illustrated by the recent recognition (at Matlock in the Peak District) of documented late-18th-century fluorspar use as a smelting flux.
c. Evaluation of field evidence at mines needs to include their geological potential to produce a variety of minerals, which may not have been documented but may have been produced as secondary products.
d. Greater recognition of the biases in historic records is needed. In in places like the Peak District, minerals such as fluorspar and barytes were extracted in significant quantities from at least as early as the 18th century from mines usually regarded as lead mines; these biases result from traditional mining law requiring detailed record being kept for lead/silver production, but not that of other associated minerals.
e. Consumption of barium minerals in the 18th century requires much more study but needs contributions from specialists in pigment production, medicine, bleaching and ceramics. For example, what did Josiah Wedgwood call what would later be known as Witherite, which he used in Jasperware in *c.*1770.

The later history of the chemical industry is little studied in relation to many minerals not just barytes and fluorspar.

f. Most significant gangue mineral working took place in the 20th century during periods of rapid technological change, some of which is well recorded for certain industries such as use of internal combustion engines, electrical equipment etc but little studied in a mining context.

g. Those gangue mines which are not re-worked earlier mines, are at the margins of archaeological interest. Yet, they justify full recording; not least at the sites of current working, which both creates and destroys archaeology. Like many coal mines and quarries, but unlike almost all metal mines, these gangue workings are relatively recent and there is little concern for their survival: this lessens their chances of being recorded adequately.

Research Aim 70: Improve our knowledge of modern mining of minerals such as fluorspar, barytes and calcite, where these products were the primary reason for the work.

Normally, because of the nature of modern mineral processing, with specific places often being used by specific companies for processing product from workings spread over wide areas, plant associated with processing of these minerals is relatively rare when compared with earlier lead extraction. This needs greater recognition and recording of 20th-century plant needs to be of high priority; currently it is undervalued and sites are disappearing fast. Selected sites should be considered for scheduling.

SALT AND EVAPORITES

Research Aim 71: Improve our knowledge of past mining for salt in England.

a. The archaeology of salt extraction is dominated by the processing of brine, and greater emphasis is required on the investigation of the surviving evidence for salt mining. Any mining sites, for which remedial work is proposed to improve surface stability, should be the subject of full assessment and recording. Existing accessible underground workings, for salt and other evaporites, should be recorded in full, and, where still active, new working should be monitored for evidence of earlier working.

b. The ephemeral nature of archaeological features at early salt mines, affected significantly by surface subsidence particularly in Cheshire, is a problem. Interpretation of the archaeological evidence would be greatly enhanced by the utilisation of photographic evidence. To that end, comprehensive cataloguing of the photographic evidence is required to supplement the written record of salt mining.

Research Aim 72: Increase our knowledge of gypsum mining in England; start with a spatial study combining historical and geological data to enable informed field recording.

a. It is known that gypsum has been mined widely in England from the medieval period until the present day. It was highly sought after for plaster and alabaster, and regional sources are known geologically. However, nationally no historical overview of the industry exists, and archaeological assessment of sites where gypsum was, or may have been produced, has not yet occurred. A search for field evidence is needed to give a basic grasp of the impact made by this industry, and the character of the remains, if any, informed by a combination of geological data, which can pinpoint the sources with historical research.

b. Any remaining surface evidence for gypsum treatment plants should be recorded as fully as possible, along with any evidence for alabaster working. This should put particular emphasis on post-medieval and earlier extraction for sculptural use, but recently abandoned and current mines should also be considered worthy of recording. Particular attention might profitably be directed to the Trent and Dove Valleys between Uttoxeter and Newark. As a starting point, a number of existing local accounts could usefully be collated.

16.3.4 Cross-cutting research themes

PREHISTORIC AND ROMAN MINING

(The majority of research aims concerning the prehistoric and Roman periods are dealt with under the raw material headings: Flint, *see* RA 37-38; Coal, *see* RA 39; Iron, *see* RA 42; Lead/silver, *see* RA 52; Tin, *see* RA 58; Copper, *see* RA 61; Gold, *see* RA 64)

Research Aim 73: Investigate the relationship between early Roman period metal mines and the involvement of the Roman military.

a. The Roman metal mine sites recently investigated in Wales and England are much earlier than previously thought. Further work is needed to find out whether this reflects military control of, and involvement in, post-Conquest mining of those sites known to have

been worked in the Late Iron Age, or earlier. Work should be undertaken to find the immediate Roman hinterland of places like Alderley Edge.

b. Investigations should be made into the Wealden iron mines to find out if they were those referred to by Caesar in 55-54BC as 'iron in the coastal districts' (i.e. near to France). If they were, research is then needed to discover when Britain became a net exporter of iron, presumably to Roman Europe. (*see* Strabo Geography iv 5, 199).

c. All Roman forts had blacksmiths, and there is increasing evidence for smelting. Evidence should be sought for military exploitation of local iron resources.

d. The locations chosen for Roman forts (e.g. Calstock and others in Cornwall, and Whitley Castle - *Epiacum* - in Cumbria) may have been influenced by the presence of local mineral resources, and this needs to be investigated. Linked with this, there should be research into whether there was early (post-invasion) military involvement in metal prospecting throughout Britain.

e. There should be greater co-operation with European colleagues to integrate our exploration of Roman mining with the work already carried out on the Continent and to explore trade routes.

SOCIAL IMPACT

Research Aim 74: Broaden the scope of archaeological research to include the social contexts of mine and quarry communities.

a. The ability of archaeology alone to explore social issues such as community, identity, class, gender and religion is limited by the form of the material we have available; for the post-medieval and later period in particular, such topics are often better served by a fusion of approaches, including historical archive research and oral history. However, within mining communities, which might be considered 'communities of occupation rather than communities of place' (Knapp 1998, xv), such themes should be more clearly detectable than in less sharply defined areas of human existence, and the material culture has potential to be useful in understanding some of the social issues associated with them. A wider engagement with the idea that the extractive industries have an archaeology of labour, as well as that of technology, would greatly enhance our progress towards understanding mining's place within past societies. A recent study of graffiti in the underground Bathstone mines, for example, has highlighted the potential for archaeologists to say something about the people who worked the mines, not just their industrial efforts (Willies et al. 2011).

b. Mining and quarrying industries, especially when enduring, made a major impact on the economy, growth and social structure of the areas affected. Increases in worker housing, and the consequent growth of major conurbations associated with large mine complexes and quarries in the 19th century, is an obvious example where social process has developed around mining. On a lesser scale, in remote parts of the Yorkshire Dales and the North Pennines, Derbyshire, Devon, Cornwall and elsewhere, subsistence strategies were often a balance between small-scale mining and farming, manifest by small hamlets and isolated settlements; while in contrast specialist housing was not often built by mine employers in these places. The exception is at remotely situated mines and quarries, which might have accommodation for workers, including barracks for itinerant miners and small terraces of cottages for families. Mine captains and agents often had more imposing houses at the heart of mining operation, and many of these structures survive as dwellings today. From the 18th century onwards, massive wealth was to be made from mining; powerful industrialist and some members of the aristocracy built huge edifices funded by mining profits and as monuments to their personal success. Long after the mines and quarries became abandoned, and their lands reclaimed for other purposes, the houses lived in by those associated with the industry at all social levels may be the only physically intact component of once vast mining landscapes. Elsewhere, ruined houses as components of relict mining landscapes, are often the least studied of the evidence, where the extractive processes, transport, power sources and ore dressing are more favoured topics. There is, therefore, much to be discovered through archaeological study of housing, about the living conditions and social processes of past mining communities, as well as the impact of mining and quarrying on the growth of urban and rural settlement. Efforts should be made to carry out integrated studies of mining and quarrying which encompasses their infrastructure, particularly the related settlement pattern. In the case of some long established mining areas, as for example the Peak District of Derbyshire, there is no distinct form of settlement linked directly to the mining industry, although there is a number of quarry villages. The integration of mining or quarrying into the historic rural landscape in such areas needs to be examined in detail.

INFRASTRUCTURE AND TRANSPORT

Research Aim 75: Expand our knowledge of the importance of mines and quarries with regards to transport systems and industrial infrastructure.

a. Mining and quarrying relied on a massive network and infrastructure for the movement of materials and products. Early trackways and packhorse routes gave way to tramways, railways, canals and road haulage to create distribution networks between mineral sources and manufacturers using the products. Harbours and ports often have their origin in the need to move minerals around the coast to other parts of Britain or for export. In short, mineral production was a vital component in the development of transport networks in England. However, transport history and archaeology have often been researched separately to the industries for which these networks were created, and some synergy is now required to advance this concept.
b. The influence of mines and quarries over those industries set up in support of them, and of others utilising and consuming their output, needs to be explored**.** Extractive industries in all historic periods were served by a number of smaller industries supplying the mines with materials and services, such as timber, fuel, explosives, iron and sundries, food for men and horses and countless other materials needed for the core business to be possible. Where mining and quarrying were major enduring components of the economic and social makeup of an area, much of the landscape and intrinsic materiality of that region has been influenced by the mines well beyond the confines of the mining activity itself. The influence of mining on woodland management, and food production in the locale would have been profound and prime users of the materials mined and quarried often sprang up near to the source.
c. Some aspects of transport are relatively well studied, but some, such as the use of pack horses, are not. There is also the use of sleds, which is known to have been responsible for creating sunken roads from upland collieries. Aerial ropeways were once widespread at a variety of extractive sites; most have been effaced but those that survive, completely or partly, need recording. A comprehensive study of transport, particularly that used before the 18th century is required. Studies of the historical data for coastal shipping have been carried out but these need to be complemented by archaeological investigation of the physical links with mining.

Research Aim 76: Use archaeological and historical research to increase our knowledge of methods and traditions used for defining mining and mineral rights and the marking of mineral boundaries.

Customary regulation of mining in some fields, and estate controlled mineral leasing in many others, required the marking of the working boundaries. Whilst there has been research into the documentary and physical evidence in some lead mining areas, such as the Pennines and parts of Northeast Wales, there has been no investigation of practice and surviving examples. Similarly, the practice of assigning specific working areas (lots, setts etc) in quarries, where identifiable, could aid site interpretation.

Acknowledgements
John Barnatt, Sallie Bassham, Peter Claughton, Mike Gill, Fred Hartley, Marcus Jecock, Ian Thomas, Peter Topping Dave Williams, for additional material and comment.

17 Bibliography

List of abbreviations used in the bibliography

ALGAO – Association of Local Government Archaeological Officers
BAR – British Archaeological Report
BCHS – Ball Clay Heritage Society
BGS – British Geological Survey
CAG – Colchester Archaeological Group
CAT – Canterbury Archaeological Trust
CATMHS – Cumbria Amenity Trust Mining History Society
CBA – Council for British Archaeology
CAU – Cornwall Archaeological Unit (now CHES)
CaAU – Cambridge Archaeological Unit
CC – County Council
CCMHS – Cannock Chase Mining Historical Society
CHES – Cornwall Historic Environment Services (formerly CAU)
CIA – Cleveland Industrial Archaeologist (published by CIAS)
CIAS – Cleveland Industrial Archaeology Society
DCNQ – Devon and Cornwall Notes and Queries
DCRS – Devon & Cornwall Record Society
DNAAS – Durham and Northumberland Architectural and Archaeological Society
DNHAS – Dorset Natural History and Archaeological Society
DNPA – Dartmoor National Park Authority
DTRG – Dartmoor Tinworking Research Group
EA – Exeter Archaeology (formerly EMAFU)
EDAS – Ed Dennison Archaeological Surveys
EH – English Heritage (Historic England from 2015)
EHAI – English Heritage Archaeological Investigation
EH AML – English Heritage Ancient Monuments Laboratory
EMAFU – Exeter Museums Archaeological Field Unit
ENPA – Exmoor National Park Authority
GCCAS – Gloucester County Council Archaeology Services
HE – Historic England
HER – Historic Environment Record
HES – Historic Environment Service
HMIMQ – His/Her Majesty's Inspector of Mines and Quarries
HMSO – Her Majesty's Stationary Office
ICE – Institute of Civil Engineers
IRIS – Index Record for Industrial Sites
JSCMC – Journal of the Shropshire Caving and Mining Club
KARG – Kent Archaeological Research Group
KCC – Kent County Council
LDNPA – Lake District National Park Authority
LMLHPS – Langton Matravers Local History and Preservation Society
LHA – Lincolnshire Heritage and Archaeology
LIHS – Leicestershire Industrial History Society
LMQT – Lakeland Mines and Quarries Trust
LUAU – Lancaster University Archaeological Unit
MRCC – Mineral Resources Consultative Committee
MPRG – Medieval Pottery Research Group
NAAL – Northern Archaeological Associates
NCMRS – Northern Cavern and Mine Research Society
NMR – National Monument Record (NRHE since 2015)
NMRS – Northern Mine Research Society
NCMRS – Northern Cavern & Mine Research Society
NSC – National Stone Centre
NPAL – North Pennines Archaeology Ltd
NRHE – National Record of the Historic Environment (England) (formerly NMR)
NYMNPA – North Yorkshire Moors National Park Authority
OA – Oxford Archaeology
OAN – Oxford Archaeology North
PDMHS – Peak District Mines Historical Society
PDNPA – Peak District National Park Authority
RAI – Royal Archaeological Institute
RCHME – Royal Commission on the Historical Monuments of England
RVBMRG – Ryedale Vernacular Building Materials Research Group
SCMC – Shropshire Caving and Mining Club
SAHS – Scarborough Archaeological Historical Society (formerly SDAS)
SIAS – Somerset Industrial Archaeological Society
SGMRG – South Gloucester Mines Research Group
TNA – The National Archive (Kew)
TUPS – Trade Union Publications Service
UMAU – University of Manchester Archaeological Unit
WA – Wessex Archaeology
WAA – Wardell Armstrong Archaeology
WCCHEAS – Worcestershire County Council Historic Environment & Archaeology Service

Bibliography

Acworth, R 1992(Winter) 'The Anthracite Seams of North Devon' *J Trevithick Soc*, 117-25

Adam, N J, Cox, P W and Chandler, J 2001 *Stover Ball Clay Works ROMPS, Teigngrace, Devon: Archaeological Assessment*. AC Archaeology report

Adams, D 2007 *The History of Limestone Mining in Church Aston and Lilleshall.* SCMC Account **25**

Adams, D R 1962 *Survey of the Metal Mines of South-West Shropshire*. Shropshire Mining Club Account **2** (and later editions)

Adams, D R 1970 *The Mines of Llanymynech Hill*. Account **14** SCMC (edited and updated by A J Preece 1992)

Adams, J 1995, *Mines of the Lake District Fells*. Dalesman

Adlung, S and Strassburger, M 2009 'The Dating of Mine Gallery Profiles' in J Silvertant (ed) *Recognition, Investigation and Preservation of ancient Mining Relics*. Maastricht/ Reichelsheim: Institute Europa Subterranea, 80-107

Ainsworth, S 2009 'Miner-Farmer Landscapes of the North Pennine Area of Outstanding Natural Beauty (AONB)' *English Heritage Research News* **11**, 10-15

Ainsworth, S and Burn, A 2009 *Grassington Lead Mines, North Yorkshire: A Rapid Assessment of the Threats posed by Road Management and Erosion*. EH Research Report **41/2009**

Agricola, G 1556 *De Re Metallica*. New York: Dover (1950 Trans by H C and L H Hoover)

Alexander, J S 1995 'Building stone from the East Midlands Quarries: Sources, transportation and usage' *Medieval Archaeol* **39**,107-35

Alexander, F 1998 *The Modern Development of the Quarrying Industry: An Introduction*. Tarmac Papers **2**, 247-52. Tarmac Ltd History Initiative Archive

Alfrey, J and Clark, C 1993 *The Landscape of Industry: Patterns of Change in the Ironbridge Gorge*. London: Routledge

Allan, J 1991 'Notes on the building stones of the cathedral (Exeter)' in F Kelly (ed) *Medieval Art and Architecture at Exeter Cathedral*. London: Brit Arch Ass, 10-18

Allan, J, Blackmore, S and Passmore, A 2010 'Archaeological investigations around Crediton Parish Church, 1984-2007' *Proc Devon Archaeol Soc* **68**, 113-98

Anderton, R, Bridges, P H, Leeder, M R and Sellwood, B W 1979 *A dynamic stratigraphy of the British Isles*. London: George Allen and Unwin

Allen, J R L 1996 'A possible medieval trade in iron ores in the Severn estuary of south-west Britain' *Medieval Archaeol* **40**, 226-30

Allen, J R L 2004a 'A medieval pottery assemblage from Magor Pill (Abergwaitha), Caldicot Level – comparative Roman to early-modern trade around the Severn Estuary and beyond' *Archaeology in the Severn Estuary* **14**, 87-110

Allen, J R L 2004b *Carrstone in Norfolk buildings: distribution, use, associates and influences*. Norfolk: Archaeopress

Allen, T Cotterill, M and Pike, G 2001 'Copperas: an account of the Whitstable copperas works and the first major chemical industry in England' *Industrial Archaeology Review,* **23: 2**, 93-112

Allason-Jones, L and Jones, J M 1994 'Jet and other materials in Roman artefact studies' *Archaeologia Aeliana* 5th series **22**, 265-72

Allason-Jones, L 2002 'The jet industry and allied trades in Roman Yorkshire' in P Wilson and J Price (eds) *Aspects of Industry in Roman Yorkshire and the North*. Oxford

Allison, W 2010 'Discoveries at Silver Gill Mine, Caldbeck' *British Mining Memoirs* **90**, 90-105

Allison, W and Murphy S 2010 'The German Mines of Caldbeck and the Discovery of an Early Primitive Wagonway' *Trans of the Cumberland and Westmorland Antiq and Archaeol Soc* **3.10**, 35-54

Almond, J K 1977 'The Nenthead and Tynedale Lead and Zinc Company Ltd, 1882-1896' *British Mining Memoirs* **5**, 22-40

Annakin-Smith, A 2006 *The Neston Collieries and Associated Industrial Workings, 1759 to 1855*. Unpublished report

Ancel, B, Cauuet, B and Cowburn, I 2000 *The Dolaucothi Gold Mines, Archaeological Appraisal, Franco-British Team*. Report for the National Trust

Andrews, A and Andrews, J 1983 'The Stafford Survey: Part 3 (Quarries and Brickworks)' *Staffs Industrial Archaeol Soc J* **11**

Andrews, P 1994 'Excavating Mines (Copa Hill, Chinflon, Kestel)' *Bull PDMHS* **12.3**, 13-21

Andrews, R W 1962 *Cobalt*. London: HMSO

Anguilano, L, Timberlake, S and Rehren, T 2010 'An early medieval lead-smelting bole from Banc Tynddol, Cwmystwyth, Ceredigion' *Historical Metallurgy* **44.2**, 85-103

Anon 1671 'An Accompt of some Mineral Observations touching the Mines of Cornwall and Devon' *Philosophical Transactions* **5**, 2096-113

Anon 1933 *Portland Stone*. London: South Western Stone Co Ltd (3rd edition 1941)

Anon 1949 *Blasting in Quarries*. Imperial Chemical Industries

Anon 1950 *The Trend of Mechanisation*. HM Inspector of Mines and Quarries Annual Report under the Quarries Act, 1894 for 1939-49, 5-8

Anon *c*.1950 *Hopton-Wood Stone - A Book For The Architect and Craftsman*. Hopton-Wood Stone Firms

Anon 1961 'Developments at Sandwith anhydrite mine' *Mine and Quarry Engineering* **27**, 100-109

Anon 1972 *The extractive industries*. Leicester: University Press

Anon 1974 *Laws of the Stannaries of Cornwall 1753*. Camborne: The Trevithick Society

Anon 1985 *Steetley at a Hundred*. Steetley plc

Anon 1988 'Survey and Excavation at Uzzicar Shaft, Barrow Mine, Keswick' *LMQT Newsletter*

Anon 1997 *Thirlmere Estate Survey, Cumbria: Archaeological Survey*. LUAU report

Anon 1998a *Thirlmere Detailed Survey, Cumbria: Shoulthwaite Hillfort and Wythburn Lead Mine*. LUAU report

Anon 1998b 'The Ecton Antler Tool' *Mining History* **13.6**, Cover Picture

Anon 1998c *Minerals in Britain. Past production…future potential. Copper*. BGS

Anon 2000a *Stickle Tarn, Great Langdale, Cumbria, Archaeological Survey Report*. OAN report

Anon 2000b *Nidderdale AONB North Yorkshire Archaeological Survey*. LUAU report

Anon 2001a *Greenside Mines Patterdale, Cumbria: Archaeological Evaluation*. OAN report

Anon 2001b *Greenside Lead Mine Glenridding, Cumbria: Archaeological Excavation, Survey and Watching Brief*. OAN report

Anon 2004 *Little Asby Scar and Sunbiggin Tarn Common, Eden District, Cumbria: archaeological survey*. OAN report

Anon 2007 *Paddy End Dressing Floors, Coniston Copper Mines*. OAN report

Anon 2010a *Coniston Copper Mines, Cumbria Conservation Management Plan*. Prepared for LDNPA on behalf of the DSTC Commoners, December 2010. Report **0091/1-10**, Archeo Environment Ltd

Anon 2010b *Penny Rigg Copper Mill, Cumbria, Conservation Management Plan*. Prepared for LDNPA on behalf of the DSTC Commoners, December 2010. Report **0091/2-10**, Archeo Environment Ltd

Anstie, J 1873 *The Coal Fields of Gloucestershire and Somersetshire*. Bracknell: Forge Books (1965 facsimile of 1873 edition)

Archaeo-Environment Ltd 2012 *Archaeological Survey and Conservation Plan for Carrock Fell Mine*. Report for the Caldbeck and Uldale Commoners

Archer, A A 1972 *Sand and Gravel, Mineral Dossier 4*. Mineral Resources Consultative Committee. London: HMSO

Arkell, W J 1947 *Oxford Stone*. London: Faber and Faber

Arkell, W J 1948 'The Building-stones of Blenheim Palace, Cornbury Park, Glympton Park and Heythrop House Oxfordshire' *Oxoniensia* **13**

Arthur, M 2002 *The Darrington Quarries Story*. Nottingham: QMJ

Arthurton, R S, Burgess, I C and Holliday, D W 1978 'Permian and Triassic' in F Moseley (ed) *The Geology of the Lake District.* Yorkshire Geological Society Occasional Publication **3**, 189-206

Ashmore, O 1969 *The Industrial Archaeology of Lancashire*. Newton Abbot: David and Charles

Ashmore, O 1982 *The Industrial Archaeology of North-west England*. Manchester: University Press

Ashworth, H W W 1970 'Report on Romano-British Settlement and Metallurgical Site' *Mendip Nature Research Committee Journal*

Ashworth, W 1986 *The History of the British Coal Industry Volume 5: 1946-1982: The Nationalized Industry*. Oxford: University Press

Aston, M A 1974 *Stonesfield Slate*. Oxford: Oxfordshire CC Museum Services

Aston, M 2000 *Monasteries In The Landscape*. Stroud: Tempus

Atkins, R 2003 *An Early Salt Making Site and Settlement at Longhill Road, March, Cambridgeshire: An Archaeological Evaluation*. Cambridge CC AFU Report **A226**

Atkinson, F 1966 *The Great Northern Coalfield 1700-1900*. Durham County Local History Society

Atkinson, G (nd) *The Canal Duke's Collieries: Worsley 1760-1900*. Swinton: Published privately

Atkinson, M 1981 *Iron ore mining in mainland Britain in the 19th and early 20th centuries and its links with the iron and steel industry, with particular reference to Cleveland, Cumbria and the south western counties of England.* Unpublished PhD thesis, University of Exeter

Atkinson, M and Baber, C 1987 *The Growth and Decline of the South Wales Iron Industry 1760-1880*. Cardiff: University of Wales Press

Austin, A 1991 'The Eskdale Copper Mine' *British Mining Memoirs* **43**, 129-32

Austin, D, Gerrard, G A M and Greeves, T A P 1989 'Tin and agriculture in the middle-ages and beyond: landscape archaeology in St Neot Parish, Cornwall' *Cornish Archaeol* **28**, 7-251

Ayris, I 1994 T*yne and Wear Specialist Conservation of Murton Colliery Koepe Winding Engine and Tower.* Unpublished report

Ayris, I M and Vickerman, D 1978 *Collieries and Coal Workings in Northumberland, 1890-1977*.

BCHS 2003 *The Ball Clays of Devon and Dorset*. St Austell: Cornish Hillside

Badcock, A 2000 *An Archaeological Desk-Based Assessment of Land at Barberfields Farm and Holdworth, South Yorkshire*. ARCUS Report **584.1**

Bailly-Maître, M-Ch 1995 *Brandes en Oisans, La mine d'argent des Dauphins (XII-XIVe s.).* Documents D'Archéologie en Rhône-Alpes 9

Bailly-Maître, M-Ch 2002 *L'argent. Du minerai au pouvoir dans la France médiévale, coll. Espaces médiévaux*. Paris: Picard

Bainbridge, J W 1994 'Coal Mines of North Northumberland II - Scremerston Triangle' *History of the Berwickshire Naturalists' Club* **46.2**, 137-78

Bainbridge, J W 1996 'Coal Mines of North Northumberland III - southern sector, Duddo to Wandylaw' *History of the Berwickshire Naturalists' Club* **46.3**, 237-71

Baker, M V, Tapper, B, Johns, C and Herring, P 2007 *England's Historic Seascapes, Scarborough to Hartlepool and Adjacent Marine Zone: Historic Seascape Characterisation*. Cornwall CC HES, Report **2007R021** for English Heritage [Web document] http://archaeologydataservice.ac.uk/archives/view/ehsscarborough_eh_2007 [accessed 20 October 2012]

Bakewell, R 1811 'Account of a Cobalt Mine in Cheshire' *The Monthly Magazine* **31**, 7-9

Ball, T K, Booth, S J, Nickless, E F P and Smith, R T 1979 'Geochemical prosecting for barite and celestite using a portable radioisotope fluorescence analyser' *Journal of Geochemical Exploration* **11**, 277-284

Bannister, N R and Bannister, D E 1993 *Historic Landscape Survey of Writtle Forest and Park.* Unpublished report, Essex Record Office

Barber, L 1998 'An Early Romano-British salt-working site at Scotney Castle' *Archaeol Cantiana* **118**, 327-353

Barber, M, Field, D and Topping, P 1999 *The Neolithic Flint Mines of England*. Swindon: English Heritage

Barber, M and Dyer, C 2005 'Scouting for shafts: aerial reconnaissance and the Neolithic flint mine at Stoke Down, West Sussex' In P Topping and M Lynott (eds) *The Cultural Landscape of Prehistoric Mines.* Oxford : Oxbow

Baring Gould, S 1900 *A Book of Dartmoor*. London: Methuen

Barker, D 2004 'The Industrialization of the Staffordshire Potteries' in D Barker and D Cranstone (eds) *The Archaeology of Industrialization*. Leeds: Maney, 204-21

Barker, D and Cranstone, D (eds) 2004 *The Archaeology of Industrialization*. Leeds: Maney Publishing

Barker, J L 1978 'Bale Hills in Swaledale and Arkengarthdale' *British Mining Memoirs* **8**, 49-54

Barnatt, J 1993a *Priestcliffe Lees Nature Reserve, Priestcliffe, Taddington, Derbyshire.* Bakewell: PDNPA Cultural Heritage Team report

Barnatt, J 1993b *Winnats Head Farm, Castleton, Derbyshire.* Bakewell: PDNPA Cultural Heritage Team report

Barnatt, J 1993c *Hassop Estate, Hassop and Rowland: Archaeological Survey.* Bakewell: PDNPA Cultural Heritage Team report

Barnatt, J 1999 'Prehistoric and Roman Mining in the Peak District: present knowledge and future research' *Mining History* **14.2**, 19-30

Barnatt, J 2002a 'Exploration and Conservation at How Grove, Dirtlow Rake, Castleton, Derbyshire' *Mining History* **15.2**, 1-40

Barnatt, J 2002b 'The Development of Deep Ecton Mine, Staffordshire, 1723-1760' *Mining History* **15.1**, 10-23

Barnatt, J 2003 'The Lower Nestus Pipe Re-entered' *Mining History* **15.3**, 15-21

Barnatt, J 2004 *An Inventory of Regionally and Nationally Important Lead Mining Sites in the Peak District.* Bakewell: PDNPA Cultural Heritage Team report

Barnatt, J 2005 *Updated Inventory of Regionally and Nationally Important Lead Mining Sites in the Peak District – November 2005.* Bakewell: PDNPA Cultural Heritage Team report

Barnatt, J 2005 *Lathkill Dale National Nature Reserve: Over Haddon, Monyash and Youlgreave Parishes, Derbyshire.* Bakewell: PDNPA Cultural Heritage Team report

Barnatt, J 2006 *Watergrove Mine, Foolow, Derbyshire. Rapid Archaeological Field Assessment.* Bakewell: PDNPA Cultural Heritage Team report

Barnatt, J 2009 'The Lead Legacy: Recent Archaeological Research and Conservation Initiatives at Peak District Mines' *Mining History* **17.4**, 1-27

Barnatt, J 2011 'High Rake Mine, Little Hucklow, Derbyshire: Excavations and Conservation at an Important Nineteenth Century Mine' *Mining History* **18.1-2**, 1-217

Barnatt, J 2012 'Silence Mine, Grindlow, Derbyshire: Investigating an 1970's Steam Engine House' British Mining ' *Mining History* **18.4**, 1-55

Barnatt, J 2013 *Delving Even Deeper: The Ecton Mines through Time*. Bakewell: PDNPA

Barnatt, J (forthcoming) *The Subterranean Industrial Legacy: Significance, Designation and Management.* Report for English Heritage

Barnatt, J, Bevan, B and Edmonds, M 2002 'Gardom's Edge: a landscape through time' *Antiquity* 76, 50-6

Barnatt, J and Dickson, A 2004 'Survey and interpretation of a limekiln complex at Peak Forest, Derbyshire and a review of early limeburning in the North-West Peak' *Derbyshire Arch J* **124**, 141-215

Barnatt, J and Doonan, R 2010 'Sourcing Lead used in the Peak District during Prehistory' *PDMHS Newsletter* **136**, 6

Barnatt, J and Leach, J 1997 'The Goyt's Moss Colliery, Buxton' *Derbyshire Archaeol J* **117**, 56-80

Barnatt, J, Huston, K, Mallon, D, Newman, R, Penny, R and Shaw, R 2013 'The Lead Legacy: An Updated Inventory of Important Metal and Gangue Mining Sites in The Peak District' *Mining History* **18.6**, 1-112

Barnatt, J and Leach, J 1997 'The Goyt's Moss Colliery, Buxton' *Derbyshire Archaeol J* **117**, 56-80

Barnatt, J and Penny, R 2004 *The Lead Legacy: The Prospects for the Peak District's Lead Mining Heritage*. Bakewell: PDNPA

Barnatt, J and Riewerts, J 1996 'The Lead Mine Related landscapes of the Peat District: Part 1 - Smelting Sites, Fuel Sources and Communication' *Mining History* **13.5**, 72-8

Barnatt, J and Rieuwerts, J 1998 'The Upper Nestus Pipes: An Ancient Lead Mine in the Peak District of Derbyshire' *Mining History* **13.5**, 51-64

Barnatt, J, Rieuwerts, J and Thomas, G H 1997 'Early use of gunpowder in the Peak District: Stone Quarry Mine and Dutchman Level, Ecton' *Mining History* **13.4**, 24-43

Barnatt, J and Smith, K 1997 *Book of the Peak District: Landscapes through time.* London: Batsford/English Heritage

Barnatt, J and Thomas, G 1998 'Prehistoric mining at Ecton, Staffordshire: a dated antler tool and its context' *Mining History* **13.5**, 72-78

Barnatt, J and Williamson, T 2005 *Chatsworth - A Landscape History.* Macclesfield: Windgather

Barnatt, J and Worthington, T 2006a *A Detailed Archaeological Assessment of Fern and Roman Caves, High Tor Rake and Hard Rake, High Tor, Matlock Bath.* Bakewell: PDNPA Cultural Heritage Team report

Barnatt, J and Worthington, T 2006b 'Using Coal to Mine Lead: Firesetting at Peak District Mines' *Mining History* **16.3**, 1-94

Barnatt, J and Worthington, T 2007a 'Post-Medieval Firesetting in British Metal Mines: The Archaeological Evidence' *British Mining Memoirs* **83**, 4-20

Barnatt, J and Worthington, T 2007b 'Firesetting at Peak District Mines: The archaeological and historical evidence' *Mining History* **16.3**

Barnatt, J and Worthington, T 2009 'Metal Mines through Time: Unravelling Archaeological Evidence at Long-Worked Mines in the Peak District' *Mining History* **17.3**, 1-124

Barnes, P and Firman, R J 1991 'Gypsum working in the parish of Orston, Nottinghamshire' *Bull PDMHS* **11.4**, 167-82

Barton, C M, Woods, M A, Bristow, C R, Newell, A J, Westhead, R K, Evans, D J, Kirby, G A and Warrington, G 2011 *Geology of south Dorset and south-east Devon and its World Heritage Coast.* Special Memoir of the British Geological Survey. Nottingham: British Geological Survey

Barton, D Bradford 1964 *The Mines and Mineral Railways of East Cornwall and West Devon.* Truro: Bradford Barton

Barton, D Bradford 1966 *The Redruth and Chasewater Railway 1824-1915.* Truro: Bradford Barton (2nd edition)

Barton, D Bradford 1967 *A History of Tin Mining and Smelting in Cornwall.* Truro: Bradford Barton

Barton, D Bradford 1969 *The Cornish Beam Engine.* Truro: Bradford Barton

Barton, D Bradford 1968a *Essays in Cornish Mining History 1.* Truro: Bradford Barton

Barton, D Bradford 1968b *A History of Copper Mining in Cornwall and Devon.* Truro: Bradford Barton Ltd.

Barton, D Bradford 1970 *Essays in Cornish Mining History 2.* Truro: Bradford Barton

Barratt, G, Marriot, J, Reid, M and White, R 2007 *A conservation Plan for the Historic Mining and Quarrying Landscape of the Clee Hills, Shropshire.* Birmingham University and English Heritage

Barry, C, de la Beche, H, Smith, W and Smith, C H 1839 *Report on the Selection of Stone for Building the New Houses of Parliament*. London: HMSO

Bartlett, S 1994 *The Mines and Mining Men of Menheniot*. Twelveheads: Twelveheads Press

Barton, R M 1966 *A History of the Cornish China-Clay Industry*. Truro: Barton

Battye, R 2004 *The Forgotten Mines of Sheffield (Especially around the Upper Don, Loxley and Sheaf Valleys)*. Sheffield: Published privately

Bayley, J, Crossley, D and Ponting, M 2008 *Metals and metallurgy: a research framework for Archaeometallurgy*. London: Historical Metallurgy Society

Bayley, J and Eckstein, K 1998 *Metalworking debris from Pentrehyling Fort, Brompton, Shropshire*. EH AML Report **13/98**

Bayliss, J M, Ineson, P R and Rorison, I H 1979 'The Extent of Belland Ground adjacent to Tideslow and Maiden Rakes' *Bull PDMHS* **7.3**, 153-7

Beadle, H L 1997 'The Quarry Industry in Teesdale' in B Chambers (ed) *Out of the Pennines*. 35-49. Killhope: Friends of Killhope

Beagrie, N 1989 'The Romano-British Pewter Industry' *Britannia* **20**, 169-91

Beasley, S M 1978 *The attribution of alabaster tomb carvings to medieval schools. Analytical and typographical problems: a further study.* Unpublished PG thesis, University of Bradford

Beaver, S H 1951 'Coke Manufacture in Great Britain: A Study in Industrial Geography' *Institute of British Geographers Transactions and Papers* **17**, 133-148

Beazer, C H G 1981 *Random Reflections of a west country master craftsman*. Published privately

Beck, J 2011 'Temple photography' *Descent* **223**, 12

Beck, T A 1844 *Anales Furnessiensis: History and Antiquities of the Abbey of Furness*. London: Payne and Foss

Beer, K E 1988 *The Metalliferous Mining Region of South-West England, addenda and corrigenda*. Keyworth: BGS

Beer, K E 1989 *British Coalminers in the Nineteenth Century: A Social History*. London

Beer, K E (ed) 2011-12 *Coal in Victorian Britain* (6 vols). London: Pickering and Chatto

Beer, K E, Neville, R G and Thompson, C H 1981 *Bibliography of the British Coal Industry: Secondary literature, Parliamentary and Departmental Papers, Mineral Maps and Plans, and a guide to sources*. Oxford

Beer, K E and Scrivener, R C 1982 'Metalliferous mineralisation' in E M Durrance and D J C Laming (eds) *The Geology of Devon*. Exeter: University Press, 117-48

Benham, A J, Cameron, D G, Harrison, D J, Evans, D J, Lott, G K and Highley, D E 2006 *Mineral Resource information in Support of National and Local Planning: Gloucestershire (comprising Gloucestershire and South Gloucestershire)*. British Geological Survey Commissioned Report **CR/05/105N**. Keyworth, Nottingham: BGS

Bennett, T 2015 *Great Wheal Vor*. Camborne: The Trevithick Society

Bentley, J I, Bond, B R and Gill, M C 2005 *Ingleton Coalfield 1600-1940*. British Mining Monograph **76**

Bentley Smith, D 2005 *A Georgian Gent. and Co. The Life and Times of Charles Roe*. Ashbourne: Landmark Publishing Ltd

Berg, T and Berg, P (trans) 2001 *R R Angerstein's Illustrated Travel Diary, 1753-1755. Industry in England and Wales from a Swedish Perspective*. London: Science Museum

Bettey, J H 1982 'Production of Alum and Copperas in Southern England' *Textile History* **13.1**, 91-98

Bettey, J H 2001 'A Fruitless Quest for Wealth: the Mining of Alum and Copperas in Dorset, *c.*1568-1617' *Southern History* **23**, 2-3

Bevan, W J and Sidebottom, P C 1995 *Rowter Farm, Castleton and Woodside Farm, Oxlow End, Peak Forest, Derbyshire*. Bakewell: PDNPA Cultural Heritage Team report

Bevan, B, Doonan, R and Gale, R 2004 'Medieval Rural Lead Working: Excavations at Linch Clough, Upper Derwent Valley, 2000-1' *Derbyshire Arch J* **124**, 113-40

Bezzant, N 1980 Out *of the Rock*. Oxford: Heinemann

Bird, R and Hirst, P 1996 *The Brimpts Tin Mines, Dartmeet*. Exeter: DTRG

Bick, D E 1971 *Old Leckhampton: Its Quarries, railways etc*. Published privately

Bick, D E 1977 *The old metal mines of Mid-Wales. Part 4, West Montgomeryshire*. Newent: The Pound House

Bick, D E 1979 'Records of the Newent Coalfield' *Gloucestershire Society for Industrial Archaeol J*, 1-8

Bick, D E 1985 *The Old Copper Mines of Snowdonia*. Newent: Pound House

Bick, D E 1989 'The Beam Engine House in Wales' *Industrial Archaeology Review* **12.1**, 84-93

Bidgood, S 1978 'A new attribution for the 'Cambrian Pottery' Jug' *Leeds Arts Calendar* **82**, 26-31

Bishop, C 2001 *Quarr Stone: an archaeological and petrological study in relation to the Roman, Anglo-Saxon and Medieval stone building industries of Southern Britain.* Unpublished PhD thesis, University of Reading

Bishop, S 2011 *Castle An Dinas, St Columb Major, Cornwall, Archaeological Survey Report*. EH Research Report **110/2011**

Blacker, J G 1995 'The stone industry of Nidderdale Part 1 Pateley Bridge' *British Mining Memoirs* **55**, 34

Blacker, J G 1996 'The stone industry of Nidderdale Part 2 Stone uses' *British Mining Memoirs* **57**, 5-33

Blacker, J G, Barley, M and Moorhouse, S 1996 'Post mediaeval iron production in Nidderdale and an association with the Ingilby and Yorke Families' *British Mining Memoirs* **57,** 134-49

Blacker, J G and Mitchell, M 1998 *The Use of Nidderdale Marble and Other Crinoidal Limestones in Fountains Abbey, North Yorkshire*. Leeds Philosophical and Literary Soc

Blacker, J G and Mitchell M, 1999a *Egglestone Marble in York Churches*. Archaeology in York Interim **22.4**

Blacker, J G and Mitchell, M 1999b 'The Use of Egglestone Marble in Durham' *Durham Arch J* **14-19**, 119-30

Blagg, T F C 1976 'Tools and Techniques of the Roman Stonemason' *Britannia* **7**, 152-172

Blagg, T F C 1990 'Building Stone in Roman Britain' in D Parsons (ed) 1990a, 33-50

Blakeman, B 2007 'Copperas: a lost local industry' *PastForward* **46**, 10-11 [PDF document] www.wlct.org/heritage-services/pf46.pdf [accessed 3 February 2014]

Blanchard, I 1995 *International Lead Production and Trade in the "age of the Saigerprozess" 1460-1560*. Stuttgart: Franz Steiner

Blaylock, S R 2000 'Excavation of an Early Post-Medieval bronze foundry at Cowick Street, Exeter, 1999–2000' *Proc Devon Archaeol Soc* 58, 1–92

Blick, C R 1991 *Early Metallurgical Sites in Great Britain*. London: The Institute of Metals

Bodman, M 2012 *Inclined Planes in the South West.* Truro: Twelveheads

Bond, G C 1924 **'**History of Early Coal- and Ironstone-mining in Nottinghamshire, and Other Notes on the Ironmaking Industry' *Trans Institution of Mining Engineers* **67,** 222-39

Bond, B 1984 'Martholme Pit, Great Harwood' *British Mining Memoirs* **25**, 31-7

Booker, F 1968 *The Industrial Archaeology of the Tamar Valley*. Newton Abbot: David and Charles

Boon, G C 1971 'Concerning the production of non-ferrous metals in Roman Britain' *Apulum* **9**, 453-500

Borlase, W 1758 *A Natural History of Cornwall*. Oxford

Borman, S 2009 *Limekilns at Newbridge Quarry.* Report for NYMNPA

Born, A 1988 'Blue slate quarrying in South Devon: an ancient industry' *Industrial Archaeology Review* **11.1**, 51-67

Born, A 1991 'Limestone, Limekilns and the Limeburning Industry North and West of Dartmoor' *Rep Trans Devonshire Ass* **123**, 213-40

Bowden, M (ed) 2000 *Furness Iron*. Swindon: English Heritage

Bowen, D Q 1994 'Late Cenozoic Wales and south-west England' *Proceedings of the Ussher Society* 8: 209-13

Bowen, D Q, Phillips, F M and Elmore, D 1994 'Chlorine-36 dating British ice-sheets' *Abstracts of the American Geophysics Union,* 1994 Fall Meeting, 226

Bowen, D Q 1999 *A Revised Correlation of Quaternary Deposits in the British Isles*. The Geological Society

Bower, A 1993 *North Derbyshire Collieries on old picture postcards*. Yesterday's Derbyshire Series **1**

Bowering, G and Flindall, R 1988 'Hard Times: A history of the Derbyshire Chert Industry' *Mining History* **13.5**, 1-32

Bowtell, H D 1979 *Reservoir railways of Yorkshire*. Blandford: Oakwood Press

Boyd-Dawkins, W 1875 'On the stone mining tools from Alderley Edge' *Proc Lit Phil Soc Manchester* **14**, 74-9

Boyd-Dawkins, W 1876 'On the stone mining tools from Alderley Edge' *J Anthropological Institute of Gt Britain and Ireland* **5**, 2-5

British Geological Survey (nd) *Cool Graphite, Borrowdale, Lake District* [Web document] www.bgs.ac.uk/research/ukgeology/borrowdale.html [accessed 29 February 2015]

British Geological Survey 2012 *Interactive map – the geology of Britain viewer.* [Web document] www.bgs.ac.uk/discoveringgeology/geologyofbritain/viewer.html

Brittan, A and Ramsey, D 2007 *The Leicestershire Slate Industry from Roman Times to closure in 1908*. LIHS Bulletin **18**. (2nd edition)

Brophy, J (forthcoming) *Nidderdale Iron.* (2nd edition)

Brooke, A (nd) *Coal Mining in the Huddersfield Area* [web document]https://undergroundhistories.wordpress.com/coal-mining-in-the-huddersfield-area/[accessed 2 February 2014]

Brook, F and Allbutt, M 1973 *The Shropshire Lead Mines*. Hartington: Moorland Publishing

Brook, M A 2002 *Nottinghamshire Bibliography: Publications on Nottinghamshire History before 1998*. The Thoroton Society of Nottinghamshire in association with the Nottingham Civic Society

Brooke, J 1980 *Stannary Tales - The Shady Side of Mining*. Truro: Twelveheads

Brooke, J 2001 *The Kalmeter Journal. The Journal of a visit to Cornwall, Devon and Somerset in 1724-5*. Truro: Twelveheads

Brooks, G 2009 'The East Cumberland Coalfield' B*ritish Mining Memoirs* **88**, 124-36

Brooks, G 2010 'An eighteenth century Westmorland Colliery' *Trans Cumberland and Westmorland Antiq and Archaeol Soc* **10**, 77-92

Brooks, T 2001 *Castle-an-Dinas, 1916-1957*. St Austell: Cornish Hillside

Brooks, T 2004 *Great Rock: Devon's last Metal Mine*. St Austell: Cornish Hillside

Brooks, T 2011 *A History of Iron Mining in Cornwall*. St Austell: Cornish Hillside

Brooks, T and Walton, J 2002 *King Edward Mine: An Illustrated Account of Underground and Surface Operations 1897-2001*. St Austell: Cornish Hillside

Broomhead, R A 2001 *Mendip Mining Rakes: A Provisional Sample Study of their Extent and Decline prepared for Mendip AONB*. Unpublished typescript

Brown, A, Bennett, J and Rhodes, E 2009 'Roman mining on Exmoor: a geomorphological approach at Anstey's Combe, Dulverton' *Environmental Archaeology* **14.1**, 50-61

Brown, G 1997 *A field investigation and survey at Hartshill Hayes*. RCHME report

Brown, I J 1964 *Ughill Fireclay Mine, Loxley Valley, Nr Sheffield.* Unpublished report

Brown, I J 1966 *'Rock had a chequered history' Shropshire Magazine,* October 1966, 30-32

Brown, I J 1968 *The Coalbrookdale Coalfield: Catalogue of Mines and Mining Bibliography*. Shropshire CC Libraries

Brown, I J (nd) *Walkers Earth mining in the Silurian Measures, Coalbrookdale*. Unpublished manuscript

Brown, I J 1975 'A Gazetteer of Ironstone Mines in the East Midlands' *Bull PDMHS* **6.2**, 107-10

Brown, I J 1976 *The Mines of Shropshire*. Hartington: Moorland

Brown, I J 1988 *Snailbeach mine stage 2 study: industrial archaeology aspects of the study area.* Unpublished report

Brown, I J 1989 'Horses in Shropshire Mines' *British Mining Memoirs* **39**, 78-88

Brown, I J 1990 'Burgam, Shropshire's Last Working Metal Mine, 1957-1963' *Bull PDMHS* **11.2**, 80-84

Brown, I J 1993a 'Snailbeach Lead Mine – The Surface Remains' *Shropshire Mining Club Account* **17**

Brown, I J 1993b 'The Buildings and Equipment used at Pennerley Mine' *Bull PDMHS* **12.2**, 50-56

Brown, I J 1998 'Ironstone working in the Coalbrookdale Coalfield' *Mining History* **13:5**, 79-88

Brown, I J 1999 *The East Shropshire Coalfields*. Stroud: Tempus

Brown, I J 2004 'Pyrites Mining in Shropshire' *Telford Hist and Arch Soc Journal* **8**, 247

Brown, I J 2006 'The NCB Full-face Tunnelling Machine' *Below: Newsletter of the Shropshire Caving and Mining Club* **2006:2**, 12-13

Brown, I J 2007 'The Madeley Wood Colliery (Halesfield and Kemberton Pits)' *Account No. 26*. Shropshire Caving and Mining Club

Brown, I J (nd) *The Harlaxton Ironstone Quarry Story 1940-1977*. Unpublished manuscript

Brown, I J (nd) *Natural Oil Seepages, Cannel and Shale Oils in England*. Unpublished notes

Brown, K, Morris, J H, Sanchez, A A P and Critchley, M 2005 *Interpreting the Ruins of Cornish Engine Houses*. Killhope: Europamines

Brunskill, R W 2006 *Vernacular buildings: an illustrated handbook*. London: Faber and Faber (1st edition 1985)

Brunskill, R W 2009 *Brick and clay building in Britain*. London: Yale University Press

Buchanan, P 1992 'Metalliferous Plant Communities; The flora of lead smelting in the Upper Nent Valley' in L Willies and D Cranstone (eds) *Boles and Smeltmills*. London: HMS

Buck, C 1998 *Preliminary Assessment of Sites of Archaeological Importance in the Tamar Valley*. Cornwall CC HES report

Buck, C 1999 *Okel Tor Works*. Truro: CAU Report **1999R047**

Buck, C 2001a *Preliminary assessment of the industrial sites of archaeological importance in the Tamar Valley-Part 1*. Extract from Journal **23** Friends of Morewellham. Cornwall CC HES Report **2001R082**

Buck, C 2001b *Preliminary assessment of the industrial sites of archaeological importance in the Tamar Valley-Part 2*. Extract from Journal **24** Friends of Morewellham. Cornwall CC HES Report **2001R083**

Buck, C 2001c *Wheal Harriet Shaft Dolcoath - Archaeological recording during site investigation works*. Cornwall CC HES Report **2001R020**

Buck, C 2002 *Devon Great Consols*. Cornwall CC HES Report **2002R069**

Buck, C 2003 *Bedford Mines: Archaeological Assessment*. Cornwall CC HES Report **2003R043**

Buck, C 2005 *Wheal Russell Mine, Devon: Archaeological Assessment*. Cornwall CC HES Report

Buck, C 2006a *Gawton Mine, Devon*. Cornwall CC HES Report **2006R023**

Buck, C 2006b *Coombe Arsenic Chimney, Harrowbarrow*. Truro: Cornwall CC HES Report **2006R038**

Buck, C 2006c *Archaeological assessment of Prince of Wales Mine*. Cornwall CC HES Report **2007R009**

Buck, C 2008a *West Prince of Wales and Wheal Brothers Mine, Harrowbarrow, Cornwall: Archaeological Assessment*. Cornwall CC HES Report **2008R057**

Buck, C 2008b *Weir Quay Smelters, Devon: Impact and Conservation Assessment*. Cornwall CC HES Report **2008R137**

Buckland, P C and Saddler, J 1990 'Ballast and Building Stone: A Discussion' in D Parsons (ed) 1990a, 114-25

Buckley, A 1987 *Tudor Tin Bounds*. Cornwall: Dyllansow Truran

Buckley, A 1994 *The Bailiff of Blackmoor 1586, Thomas Beare*. Camborne: Penhellick

Buckley, A 1997 *A History of South Crofty Mine*. Dylanslow Truran

Buckley, A 2001 *Medieval Cornish Stannary Charters 1201-1507*. Camborne: Penhellick

Buckley, A 2005 *The Story of Mining in Cornwall – A World of Payable Ground*. Truro: Cornwall Editions

Buckley, A 2010 *Dolcoath Mine: A History*. Camborne: Trevithick Society

Buckley, A 2015 *Wheal Bassett: Five Centuries of mining at Carnkie*. Camborne: The Trevthick Society

Buckley, R and Howard, M 1995 'Greensward Mine and its Pumps' *Bull PDMHS* **12.6**, 68-81

Budd, P and Gale, D 1993 *Archaeological Survey of an Early Mine Working at Wheal Coates, near St. Agnes, Cornwall*. University of Bradford

Budd, P and Gale, D 1994 'Archaeological survey of an early mineworking at Wheal Coates near St Agnes, Cornwall' *Cornish Archaeol* **33**, 14–21

Budd, P, Hagerty, R, Ixer, R A, Scaife, B and Thomas, R 2000 *Copper deposits in South-West England identified as a source of Copper Age Metalwork*. [Web document] http://goodprovenance.com/provenance.html

Budd, P and Gale, D (eds) 1997 *Prehistoric Extractive Metallurgy in Cornwall*. Truro: Cornwall CC

Buglass, J and Brigham, T 2008 *Rapid Coastal Zone Assessment, Whitby to Reighton*. Humber Archaeology Report **238** for English Heritage (Project 3729), [Web document] http://www.english-heritage.org.uk/publications/rczas-whitby-to-reighton/rczas-vol4-whitby-reighton-report-gazetteers.pdf [accessed 3 January 2015]

Bullen, L J 2000-2008 *Mining in Cornwall*. (various vols).

Bunch, B and Fell, C I 1949 'A Stone-axe Factory at Pike of Stickle, Great Langdale, Westmorland' *Proc Prehistoric Soc* **15**, 1-20

Bunyack, D 1998 *Frothers, Bubbles and Flotation: a survey of flotation milling in the twentieth-century metals industry*. Denver, Colorado: National Park Service

Burgess, I C and Holliday, D W 1979 *Geology of the country around Brough-under-Stainmore*. Memoir of the Geological Survey of Great Britain. London: HMSO

Burgess, P 2008 *Surrey's Ancient Stone Mines*. Published privately

Burgess, P M 1983 'The surveying of the Chaldon Bottom firestone quarries, near Merstham, Surrey: Interim Report' *Bull Subterranea Britannica* **18**, 19-20, 22

Burgess, P M 1987 'Quarry tools and other artefacts from the Chaldon and Merstham quarries, Surrey' *Bull Subterranea Britannica* **23**, 26-29

Burgess, P M 1994a 'Carthorse Quarry, Godstone, Survey and site investigation 1990-1' *Bull Subterranea Britannica* **30** 21-34

Burgess, P M 1994b 'The use of plate rails in the Godstone firestone quarries – some recent discoveries' *Proc Croydon Natural History and Scientific Soc* **18.4**, 10-107

Burl, A 1976 *The stone circles of the British Isles*. London: Yale University Press

Burl, A 1995 *A guide to the stone circles of Britain, Ireland and Brittany.* London: Yale University Press

Burl, A 2007 *A brief history of Stonehenge*. London: Robinson

Burnard, R 1887-90 'On the Track of the "Old Men", Dartmoor Parts 1 and 2' *Trans Plymouth Institution* **10**, 95-112; 223-42

Burnett, A M and Bland, R F 1986 *Coin Hoards from Roman Britain Volume 6*. British Museum Occasional Paper **58**, 9

Burrow, J C and Thomas, W 1893 *'Mongst Mines and Miners': or Underground Scenes by Flashlight*. (reprinted 1965)

Burt, R 1982 *A Short History of British Ore Preparation Techniques in the Eighteenth and Nineteenth Centuries*. Lelielaan, Netherlands: De Archæologische Pers

Burt, R 1984 *The British Lead Mining Industry*. Redruth: Dyllansow Truran

Burt, R 1988 'Arsenic - Its Significance for the Survival of South Western Metal Mining in the late Nineteenth and early Twentieth Centuries' *J Trevithick Soc* **15**, 5-26

Burt, R 1989 'The Non-ferrous Mining Industries and Proto-industrialisation' International Mining History Congress, Bochum, Germany

Burt, R 1995 'The Transformation of the Non-Ferrous Metal Industries in the Seventeenth and Eighteenth Centuries' *Economic History Review* **48.1**, 23-45

Burt, R, Burnley, R, Gill, M C and Neill, A *Mining in Cornwall and Devon: Mines and Men*. Interactive CD-ROM

Burt, R, Waite, P and Burnley, R 1982 *The Cumberland Mineral Statistics* 1845-1913. Exeter: University Press

Burt, R, Waite, P and Burnley, R 1984 *Devon and Somerset Mines*. Exeter: University Press

Burt, R, Waite, P and Burnley, R 1987 *Cornish Mines*. Exeter: University Press

Burt, R, Waite, P and Burnley, R 1990 *The Mines of Shropshire and Montgomeryshire etc*. Exeter: University Press

Burt, R and Wilkie, I 1984 'Manganese Mining in the south west of England' *J Trevithick Soc* **11**, 18-40

Bushe-Fox, J P 1915 *Excavations at Hengistbury Head, Hampshire in 1911-1912*. Report **3**. London: Society of Antiquaries

Butler, D B 1913 *Portland Cement Its manufacture, Testing and Use*. London: E F N Spon (3rd edition)

Butler, J 1997 *Dartmoor Atlas of Antiquities: 5, the 2nd millennium BC*. Tiverton: Devon Books

Cadman, G E 1997 *Easton on the Hill Ironstone Quarrying Reconnaissance Survey.* Unpublished report for Northants SMR

Cadman, D and Audouy, M 1990 'Recent excavations on Saxon and Medieval quarries in Raunds, Northamptonshire' in Parsons 1990a, 187-206

Cahill, N 2000 *Hayle Historical Assessment Cornwall*. Truro: CAU report for EH

Cahill, N 2002a *Cornwall Industrial Settlements Initiative Portreath (Camborne/Redruth Area)*. Report for Cornwall CC

Cahill, N 2002b *Cornwall Industrial Settlements Initiative Devoran (Truro Area)*. Report for Cornwall CC

Cahill, N 2002c *Cornwall Industrial Settlements Initiative St Just.* Report for Cornwall CC

Cahill, N 2002d *Cornwall Industrial Settlements Initiative: Redruth and Plain-an-Gwarry*. Report for Cornwall CC

Cahill, N 2002e *Cornwall Industrial Settlements Initiative: Camborne*. Report for Cornwall CC

Cahill, N 2002f *Cornwall Industrial Settlements Initiative: Tuckingmill and Roskear*. Report for Cornwall CC

Cahill, N 2004 Cornwall Industrial Settlements Initiative: Nanpean. Report for Cornwall CC

Cahill Partnership and Cornwall HES 2005a *Cornwall Industrial Settlements Initiative: Bugle (Hensbarrow Area)*. Report for Cornwall CC **2005R034**

Cahill Partnership and Cornwall HES 2005b *Cornwall Industrial Settlements Initiative: Roche (Hensbarrow Area)*. Report for Cornwall CC **2005R035**

Cahill Partnership and Cornwall HES 2005c *Cornwall Industrial Settlements Initiative: Stenalees (Hensbarrow Area)*. Report for Cornwall CC **2005R036**

Calendar of Close Rolls, Richard II. (6 vols). Public Record Office, London (1914-1927)

Callender, R M 1990 *Gold in Britain*. Beaconsfield: Goldspear

Callister, W D 2002 *Materials science and engineering: an introduction.* Hoboken USA: John Wiley and Sons

Calvert, A G 1915 *Salt in Cheshire*. London: E and F N Spon

Calvert, J 1853 *The Gold Rocks of Great Britain and Ireland*. Chapman and Hall, London (facsimile reprint, Goldpanners Association, Beaconsfield)

Cameron, A D 2005 *Slate From Coniston*. CATMHS

Cameron, D G, Cooper, D C, Johnson, E W, Roberts, P D, Cornwell, J D, Bland, D J and Nancarrow, P H A 1993 *Mineral exploration in the Lower Palaeozoic rocks of south–west Cumbria. Part 1: regional surveys*. BGS Mineral Reconnaissance Programme Report **128** [PDF document] www.bgs.ac.uk/downloads/start.cfm?id=1886 [accessed 23 August 2012]

Cameron, D G and Bland, D J 1994 *An appraisal of the gold potential of mine dumps in the North Molton area, North Devon.* BGS Mineral Reconnaissance Programme Open File Report **15** [PDF document] www.bgs.ac.uk/downloads/start.cfm?id=1977 [accessed 16 August 2012]

Camm, G S 1995 *Gold in the counties of Devon and Cornwall*. St Austell: Cornish Hillside

Carew, R 1602 *The Survey of Cornwall.* London (2004 reprint, DCRS)

Carey, C 2000 *Ausewell Wood Geochemical Survey: Interim Report.* Unpublished report

Carey, C 2005 *Geochemical Survey and Metal Working on Archaeological Sites*. Exeter: University Press

Carlisle, D and Gill, M C 2004 'Swaledale's Hydraulic Engines' *in* P Claughton (ed) 33-5

Carlon, C 1979 *The Alderley Edge Mines*. Altrincham: Sherratt

Carlon, C J 1981a 'The Gallantry Bank Copper Mine, Bickerton, Cheshire' *British Mining Memoirs* **16**

Carlon, C J 1981b 'The Eardiston Copper Mine, Shropshire' *Bull PDMHS* **8.1**, 29-42

Carlon, C J and Dibben, N J 2012 *The Alderley Edge Mines*. Nantwich: Published privately

Cassell, M 1986 *The Readymixers: The story of RMC (Ready Mixed Concrete) 1931-1986*. London: Pencorp Books

CAT, the Newsletter of the Cumbria Amenity Trust Mining History Society

Catell, J 2011 'Surveying Industrial Heritage' *English Heritage Conservation Bulletin* **67**, 11

Catt, J A 1988 *Quaternary Geology for Scientist and Engineers*. Chichester: Ellis Horwood Limited

Cauuet, B 1995 *Les mines d'Or gauloises du Limousin*. Limoges: Association Culture et Patrimoine en Limousin

Cavanagh, N, and Town, M 2009a *Nenthead Mines, Alston, Cumbria Phase Ill: Part 7 Smeltmill Complex.* NPAL Interim Report.

Cavanagh, N, and Town, M 2009b *Nenthead Mines, Alston, Cumbria Phase Ill: Part 2 Ancillary Buildings* NPAL Interim Report.

Cavanagh, N, and Town, M 2009c *Nenthead Mines, Alston, Cumbria Phase Ill: Part 3 Dressing Floors*. NPAL Interim Report.

Chadwick, A M and Evans, H 2000 'Reading Roystone's Rocks: Landscape Survey and Lithic Analysis from Test Pitting at Roystone Grange, Ballidon, Derbyshire, and its Implications for Previous Interpretations of the Region' *Derbyshire Arch J* **120**, 101-122

Challis, K 1998 *Stanley Grange, Derbyshire: Interim Excavations Report and Post-Excavation Assessment.* Trent and Peak Archaeological Unit Report **SGD3**

Chaloner, W H 1954 'Charles Roe of Macclesfield (1715-81): an Eighteenth-Century Industrialist. Part II' *Trans Lancashire and Cheshire Antiquarian Soc* **63**, 52-86

Chambers, B (ed) 1992 *Men, Mines and Minerals of the North Pennines*. Killhope: Friends of Killhope

Chapman, D 1997 'Great Orme smelting site, Llandudno' *Archaeology in Wales* **37**, 56–57

Chapman, M 1987a 'The Somerset Coal Canal – A Cartographic Survey' *J Bristol Industrial Archaeol Soc* **20**

Chapman, M 1987b 'The Somerset Coal Canal Project' *J Bristol Industrial Archaeol Soc* **20**

Chapman, N A 1983 'A Certain Freehold Mineral Estate Known as the Fox Oak Colliery' *British Mining Memoirs* **23,** 34-9

Chapman, N A 1987 'The Cannock and Huntington Sinking' *British Mining Memoirs* **34**, 35-43

Chapman, N A 1993 'Cleveland Drilling Machines' *British Mining Memoirs* **48**,104-27

Chapman, N A 1994 'Heath Colliery Co., West Bromwich, Staffs' *British Mining Memoirs* **50**, 6-23

Chapman, N A 1995 'Bournehills Colliery, Rowley Regis, Staffordshire' *British Mining Memoirs* **55**, 41-6

Chapman, N A 1996 'Blakeley Hall and Bromford Collieries, Oldbury, Staffs' *British Mining Memoirs* **57**, 125-33

Chapman, N A 1997a *A history of the Sandwell Park Collieries*. Heartland

Chapman, N A 1997b 'Fairoak Colliery, Hednesford, Staffordshire' *British Mining Memoirs* **59**, 93-6

Chapman, N A 1997c 'Brereton Collieries' *British Mining Memoirs* **59**,156-61

Chapman, N A 1999a 'Old Hill or Pearson's Colliery, Rowley Regis' *British Mining Memoirs* **63**, 56-63

Chapman, N A 1999b 'The Rowley Hall Colliery, Rowley Regis, Staffordshire' *British Mining Memoirs* **63**, 64-73

Chapman, N A 1999c *A History of Coal Mining Around Halesowen*. Heartland

Chapman, N A 2000 'Leighs Wood Colliery' *British Mining Memoirs* **67** , 26-34

Chapman, N A 2004 'The Brades Coal and Steel Works, Oldbury, Staffordshire' *British Mining Memoirs* **75**, 47-57

Chapman, N A 2014 'Warwickshire Coal Mining' *British Mining Memoirs* **98**, 34-40

Chapman, S K 1975 'Excavations at the Boulby Alum Works' *Cleveland Industrial Archaeologist* **2**, 25-32

Chapman, S 1998 *The Loftus Mines*. Cleveland Ironstone Series, Guisborough: Peter Tuffs

Charlton, D 2006 *The Roots of Judy Woods: and archaeological assessment*. Carried out by the Department of Archaeological Sciences at the University of Bradford, CD publication, Bradford: Friends of Judy Woods

Cheetham, F 1984 *English Medieval Alabasters*. Oxford: Phaidon (2nd edition published by Boydell, 2005)

Cheetham, F 2001 *The Alabaster Men: Sacred Images From Medieval England*. London: Daniel Katz Ltd

Cheetham, F 2003 *The Alabaster Images of Medieval England (Museum of London Medieval Finds 1150 - 1450)*. Woodbridge: Boydell Press

Chitty, G 1996 *The Alum Industry: recommendations for protection (Step 4 Report)*. Report for the English Heritage Monuments Protection Programme

Chitty, G 2001 *Lime, cement and plaster industries Step 4 Report.* Report for the English Heritage Monuments Protection Programme

Christiansen, C 2010 *Historical Environment Landscape Survey at Worcestershire Geological Champions Sites*. WCCHEAS Report **1783**

Church, R 1986 *The History of the British Coal Industry Volume 3 Victorian Pre-Eminence*. Oxford: University Press

Claris, P, Quatermaine, J and Wooley, A R 1989 'The Neolithic Quarries and Axe Factory Sites of Great Langdale and Scafell Pike: A New Field Survey' *Proc Prehistoric Soc* **55**, 1-25

Clark, S 1995 *Mining and Quarrying in the Teign Valley*. Newton Abbot: Orchard

Clarke, W G 1915 *Report on the excavations at Grime's Graves, Weeting, Norfolk, March-May 1914*. Prehistoric Society of East Anglia

Clarke, M, Gregory, N and Gray, A 2012 *Earth Colours: Mendip and Bristol Ochre Mining*. Mendip Cave Registry

Claughton, P F 1975 'The Fullabrook Mine' *Plymouth Min and Mining Club J* **6.1**, 4-5

Claughton, P F 1989 'Mining in the Parishes of East Buckland and Charles, North Devon' *British Mining Memoirs* **39**, 4-13

Claughton, P F 1991' Mining in North Devon prior to1800' *Bull PDMHS* **11.4**, 189-192

Claughton, P 1994 *A List of Mines in North Devon and West Somerset*. Oldham: Crymych

Claughton, P 1996 'The Lumburn Leat – evidence for new pumping technology at Bere Ferrers in the 15th century' *Mining History* **13.2**, 35-40

Claughton, P 1997a 'Lead and Silver Mining' in M Atkinson (ed) *Exmoor's Industrial Archaeology*. Tiverton: Exmoor Books, 73-102

Claughton, P 1997b 'The Gourt Mine Engine House' Mining' in M Atkinson (ed) *Exmoor's Industrial Archaeology*. Tiverton: Exmoor Books, 61-65

Claughton, P 1997c 'Gold at North Molton' *Exmoor Mines Research Group Newsletter* **10**, 2-7 [Web document] http://people.exeter.ac.uk/pfclaugh/mhinf/nm_gold.htm [accessed 16 August 2012]

Claughton, P (ed) 2004a *Water Power in Mining: Mining History*. Special issue **15.4-5**

Claughton, P 2004b *The Combe Martin Mines*. Combe Martin Local History Society (revised edn)

Claughton, P 2005 'New Techniques, New Sources: The British Steel Industry and its Ore Supply, 1850-1950' *Proceedings of the 1st International Conference of Paleosiderurgy* Donostia/San Sebastian, Spain, 277-90

Claughton, P 2009 'Mining, Quarrying, Archaeology and the Historic Environment: The Evidence for the Early Part of the Medieval Period up to 1200' *Mining History* **17.4**, 40-5

Claughton, P 2010a 'Mining Law in England and Wales' *British Mining Memoirs* **90**, 161-71

Claughton, P 2010b 'Mining, Landscapes and underground Archaeology' in J Silvertant (ed) *Mining Archaeological Research: Interdisciplinary Methodology*. Valkenburg aan de Geul/Freiberg: Institute Europa Subterranea, 6-13

Claughton, P 2011 'Mineral Resources' in J Crick and E van Houts (eds) *A social History of England 900-1200*. Cambridge: University Press, 56-65

Claughton, P and Smart, C 2010 'The Crown silver mines in Devon: capital, labour and landscape in the late medieval period' *Historical Metallurgy* **44.2**, 112-25

Clavering, E 1994 'Coalmills in Tyne and Wear Collieries: The use of the waterwheel for mine drainage 1600-1750' in T Ford and L Willies (eds) 1994, 124-32

Clayton, R E, Scrivener, R C and Stanley, C J 1990 'Mineralogical and preliminary fluid inclusion studies of lead-antimony mineralisation in north Cornwall' *Proceedings of the Ussher Society* **7.3**, 258-62

Cleasby, J V, Pearse, G E, Grieves, M and Thorburn, G 1975 'Shaft-sinking at Boulby mine, Cleveland Potash, Ltd' *Trans Institution of Mining and Metallurgy* Section A.84, A7-A28.

Cleasby, L 1995 'Limekilns in Sedburgh, Garsdale and Dent' *Current Archaeology* **145**, 16-20

Cleaver, D, Coulter, J, Slade, P, Waters, E and White, D 1994 *Bideford Black: The History of a Unique Local Industry*. Bideford: Sound Archives North Devon

Cleere, H 1970 *The Romano-British industrial town at Bardown, Wadhurst*. Sussex Archaeol Soc Occasional Paper 1

Cleere, H and Crossley, D 1995 *The Iron Industry of the Weald*. Cardiff: Merton Priory Press (2nd edition)

Clifton-Taylor, A 1972 *The Pattern of English Building*. London: Faber and Faber

Clifton-Taylor, A and Ireson, A S 1983 *English Stone Building*. London: Victor Gollancz

Clough, R T 1962 (1980) *The Lead Smelting Mills of the Yorkshire Dales and Northern Pennines. Their Architectural Character, Construction and Place in the European Tradition*. Keighley: Published privately (2nd edition 1980)

Cole, R 2001 *Greensplat Pit Extension, Cornwall - Archaeological and Historical Assessment*. CAU Report **2001R044**

Cole, R 2005 *The Lovering China Clay Dry, Charlestown, Cornwall - Archaeological Assessment*. CAU Report **2005R032**

Cole, R 2007 *Wheal Rashleigh China-Clay Dry, St Blazey, Cornwall - Archaeological Assessment*. Cornwall CC HES Report **2007R025**

Collins, R S 1972 *Barium Minerals*. London: HMSO

Cook, A F 2013 'Purley Chase Manganese Mine, Mancetter, Warwickshire' *Mining History* **18:5**, 1-6

Cook, C B and Owens, J S 1994 'The Ironstone Calcining Kilns in Scugdale' *CIA* **22**, 1-11

Cook, R, Greeves T and Kilvington C, 1974 'Eylesbarrow (1814-1852) - a study of a Dartmoor tin mine' *Rep Trans Devonshire Ass* **106**, 161-214

Coope, G R 1979 'The Influence of Geology on the Manufacture of Neolithic and Bronze Age Stone Implements in the British Isles' in T H McKClough and W A Cummins (eds) 1979 98-101

Cooper, D 1998 'Gold in Britain - New prospecting methods and new discoveries' *Earthwise* **12**, 24-25 [PDF document] www.bgs.ac.uk/downloads/start.cfm?id=102 [accessed 16 August 2012]

Cooper, N J 2006 *The Archaeology of the East Midlands*. Leicester: University of Leicester Archaeological Services [Web Document] www.english-heritage.org.uk/publications/archaeology-east-midlands/em-res-framework.pdf [accessed 26 February 2012]

Cooper, R D 1977 'Quarrying in the Hambleton Hills, North Yorkshire: the Problems of Identifying Disused Workings' *Industrial Archaeology Review* **1.2**, 164 -70,

Cooper, T 2008 *Laying The Foundations: A history and archaeology of the Trent Valley sand and gravel industry*. CBA Report **59**

Cooper Key, A 1896 *Mining Journal* (6 Jul1896), 734

Cooper, A H and Saunders, J M 2002 'Road and bridge construction across gypsum karst in England' *Engineering Geology* **65.2-3**, 217–223

Cooper, M P and Stanley, C J 1990 *Minerals of the English Lake District: Caldbeck Fells*. London: Natural History Museum

Cope, J C W, Ingham, J K and Rawson, P F (eds) 1992 *Atlas of Palaeogeography and Lithofacies*. Memoir **13**. London: Geological Society of London.

Cordiner, R and Brook, A (in press 2015) *An atlas of Sussex building stones*. Worthing: Cordiner

Corin, J 1992 *Levant – A Champion Cornish Mine*. Camborne: The Trevithick Society

Corin, J and Joseph, P 2013 *Levant: A Champion Cornish Mine*. Camborne: The Trevithick Society

Cornwell, J 2001 *Collieries of Somerset and Bristol*. Ashbourne: Landmark

Cornwell, J 2003 *The Bristol Coalfield*. Ashbourne: Landmark

Coulson, M J (ed) 2005 *Stone in Wales: papers from the Welsh Stone Conference 2002*. Cardiff: Cadw

Court, W H B 1937 'A Warwickshire Colliery in the Eighteenth Century' *Economic History Review* **7.2**, 221-8

Cox, C 2000 *Survey of Early Coal Mining, North East Derbyshire*. Report

Cowell, R W 2005 'Prehistoric Hunter-Gatherers on Alderley Edge' in S Timberlake and A Prag (eds) 2005

Craddock, B 1994 'Drawing Ancient Mines' *Bull PDMHS* **12.3**, 9-12

Craddock, P T 1995 *Early Metal Mining and Production*. Edinburgh: University Press

Craddock, B and Craddock, P 1996 'The Beginnings of Metallurgy in South-West Britain: Hypotheses and Evidence' *Mining History* **13.2**, 52–63

Craddock, P T, Cowell, M R, Leese, N and Hughes, M J 1983 'The trace element composition of polished flint axes as an indicator of source' *Archaeometry* **25**, 135-163

Craig, G Y 1991 *Geology of Scotland*. London: Geological Society of London

Cranstone, D 1986 'The Washing Floors at Killhope Lead Mine, County Durham: An Interim Report' *Bull PDMHS* **9.5**, 283-305

Cranstone, D 1989 'The Archaeology of Washing Floors: Problems and Potentials' *Industrial Archaeology* **12.1**, 40-9

Cranstone, D 1990 *Old Gang and Surrender Lead Smelting Mills: Archive Report 1990 Season*. Cranstone Consultancy report

Cranstone, D 1991 *Old Gang and Surrender Lead Smelting Mills: Archive Report 1991 Season*. Cranstone Consultancy report

Cranstone, D 1992a *Monuments Protection Programme: The Lead Industry. Step 1 Report*. Cranstone Consultancy report for EH MPP

Cranstone, D 1992b 'To Hush or Not to Hush: Where, When, and How?' in B Chambers (ed) 41-8

Cranstone, D 1992c 'Mining Sites in Britain: Priorities for Research and Preservation' *Institute of Mining History and Archaeology Newsletter* **3**, 6-8

Cranstone, D 1993a *Monuments Protection Programme: The Copper Industry*. Step 1 report for English Heritage.

Cranstone, D, 1993b *Monuments Protection programme, minor metals and vein minerals*. Step 1 report for English Heritage. Cranstone Consultancy

Cranstone, D 2001 *Monuments Protection Plan: Iron and Steel Industries – Report on Step 3 Consultation*. Report for English Heritage

Cranstone, D 2002 *Monuments Protection Plan: Iron and Steel Industries – Introduction to Additional Step 3 Assessments*. Report for English Heritage

Cranstone, D 2005 'After Industrial Archaeology' in Casella, E C and Symonds, J (eds) *Industrial Archaeology: Future Directions*. New York: Springer

Cranstone, D 2007 *Whitehaven Coast Archaeology Survey*. Cranstone Consultants and Ironbridge Archaeology for the National Trust

Cranstone, D 2012 'The Panhouse as Cradle of Industry: Coastal Saltmaking and the 'Long Industrial Revolution', in H Harnow, D Cranstone, P Belford and L Møst-Madsen (eds) *Across the North Sea: later historical archaeology in Britain and Denmark, c.1500-2000*. University Press South Denmark, 159-174 [Web document] issuu.com/ecosal-atlantis/docs/across_the_north_sea_cranstone [accessed 14 October 2012]

Cranstone, D and Newman, R 1999 *Monument Protection Programme Quarrying Industry Step 3 (Revised): Introduction to site assessments*. LUAU Report **1999-00/(007)/AUA8869**

Craven, M and Stanley, M 1982 *The Derbyshire country house*. Matlock: Derbyshire Museum Service

Crew, P and Crew, S (eds) 1990 *Early Mining in the British Isles: Proceedings of the Early Mining Workshop at Plas Tan y Bwlch, Snowdonia National Park Study Centre, 17–19 November 1989*. Plas Tan y Bwlch Occasional Paper **1**

Critchley, M 1984 'The History and Workings of the Nenthead Mines, Cumbria' *Bull PDMHS* **9.1**

Critchley, M F and Wilson, P J 1975 'Holme Bank chert mine (Bakewell)' *Mining History* **6.1**

Crockett, R N 1973 *Mineral Resources Consultative Committee Mica, Mineral Dossier, No 15*. London: HMSO

Crockett, R N 1975 *Mineral Resources Consultative Committee Slate, Mineral Dossier, No 12*. London: HMSO

Crombleholme, R, Stuckey, D and Whetmath, C F D 1967 *Callington Railways*. Bracknell: West Country Handbooks

Crosby, A 2001 'Briquetage containers from Ingoldmells Beach, Lincolnshire' in Lane and Morris (eds) 2001

Crosby, D D B and Mitchell, J G 1987 'A survey of British metamorphic hone stones of the 9th to 15th centuries AD in the light of potassium-argon and natural remanent magnetization studies' *Arch Science J* 14.5, 483-506

Crossley, D W 1981 'Medieval iron smelting' in D W Crossley (ed) *Medieval Industry*, 29-41. York: CBA

Crossley, D W 1988 *Hogget Gill Lead Smelting Mill, Hartsop: Survey and Archive Report, with Recommendations, for the National Trust.* Cranstone Consultancy report

Crossley, D 1990 *Post Medieval Archaeology in Britain*. Leicester: University Press

Crossley, D 2012 'An Introduction to the Archaeology of the Glass Industry: The Monuments Protection Programme Step 1 Report' *Industrial Archaeology Review* **34.1**, 24–36

Crossley, D and Kiernan, D 1992 'The lead-smelting mills of Derbyshire' *Derbyshire Archeaol J* **112**, 6-47

Crowson, A 2001 'Excavations at Middleton, Norfolk' in Lane and Morris (eds) 2001

Cubbon, B 2008 'Bideford Black' *The Mine Explorer* **6**, 159-69 CATMHS

Cubbon, B 2013 'Barrow Salt' *Newsletter of the Cumbria Amenity Trust Mining History Society* **113**, 23-27

Cubbon, B 2015 *Barrow Salt.* Published privately

Cunnington, M E 1923 *The Early Iron Age site at All Cannings Cross, Wiltshire*. Devizes: George Simpson

Curwen, E C 1937 'Querns' *Antiquity* **11**, 133-51

Curwen, E C 1941 'More about querns' *Antiquity* **15**, 15-32

Curwen, E and Curwen, E C 1926 'Harrow Hill Flint-Mine Excavation 1924-1925' *Sussex Archaeol Collects* **67**

Czajkowski, M 2000 'The Kirkstead (Woodhall Spa) Coalfield' *Lincolnshire Hist Archaeol* **35**, 57-63

Daniel, P and Murless, B J 1993 'Limekilns at Warren Bay, Old Cleeve, Watchet, West Somerset' *Somerset Ind Arch Soc Bulletin* **65**, 15-22

Darling, M and Precious, B 2001 'A saltern at Gold Dyke Bank, Wrangle, Lincolnshire' in T Lane and E L Morris (eds) 2001

Darlow, E and King, T 1995 *Health and Safety in Quarries: A Hundred Years of Law*. Health and Safety Executive

David, R G and Brambles, G W 1992 'The Slate Quarrying Industry in Westmorland: Part Two: A Field Survey of Selected Sites in Troutbeck and Longsleddale' *Trans Cumbria Westmorland Antiquarian Archaeol Soc* **92**, 213

Davies, A and Hudson, L 2001 *The Wigan Coalfield.* Stroud: Tempus

Davies, E H 1902 *Machinery for Metalliferous Mines*. London: Crosby Lockwood and Son

Davies, G, May, R, and Claughton, P 2010 *Hard Rock Aggregates and Subterranean Archaeology – An Assessment*. Report by ARCUS for English Heritage

Davies, G, Stenton, M and Smith, M 2014 *The Physical Landscape Legacy: an assessment of the Nottinghamshire coalfield (6742 PILS)*. Report by ArcHeritage for English Heritage

Dewey, H and Dines, H G 1923 *Tungsten and Manganese Ores*. Memoirs of the Geological Survey, Special Reports on the Mineral Resources of Great Britain **1**. London: HMSO

Dewey, H and Eastwood, T 1925 Special Reports on the Mineral Resources of Great Britain: Copper ores of the Midlands, the Lake District and the Isle of Man. *Memoirs Geol Survey G B*. **30** London: HMSO

Dickinson, J M 1965 'The Dales Chemical Company' *NCMRS Memoirs,* 1965, 1-6

Dickinson, J M 1978 'Buckden Out Moor Lead Smelting Mill' *British Mining Memoirs* **8**, 38-9

Dickinson, J M, Gill, M C and Martell, H M 1975 'Lumb Clough Lead Smelting Mill, Sutton-in-Craven, Yorkshire' *British Mining Memoirs* **1**, 1-10

Dickinson, J M and Gill, M C 1983 *The Greenhow Lead Mining Field*. British Mining Monograph **21**

Dickinson, J M and Holding, J E 1965 'Coal and Iron Working in Upper Airedale' *NCMRS Memoirs,* 1965, 42-46

Dines, H G 1956 *The Metalliferous Mining Region of South-West England.* (2 vols.) London: HMSO (2nd edition 1969)

Dines, H G 1958 'The West Shropshire Mining Region' *Bull Geological Survey GB,* **14**

Dix, B 1979 'Roman Lime Burning' *Britannia* **10**, 261-2

Dixon, D 1983 *Mining and the Community in the Parishes of North Molton, South Molton, Molland and Twitchen, Devonshire* (2 vols). Unpublished post-graduate thesis

Dixon, D 1997 'Copper and Gold Mining' in M Atkinson (ed) *Exmoor's Industrial Archaeology*. Tiverton: Exmoor Books, 41-72

Dixon, T, Matthews, A, Pye, A R and Slater, W D 1989 *Gawton Mine and Arsenic Works. The Field Survey 1988.* EA report

Donald, M B 1955 *Elizabethan Copper: The History of the Company of Mines Royal, 1568-1605*. London: Pergamon

Donald, M B 1961 *Elizabethan Monopolies: The History of the Company of Mineral and Battery Works, 1568-1604*. London: Oliver and Boyd

Donkin, R A 1976 'Changes in the Early Middle Ages' in H C Darby (ed) *A New Historical Geography of England Before 1600.* 75-135

Doonan, R and Eley, T 2000 'The Langness Ancient Mining Survey', in T Darvill (ed) *Billown Neolithic Landscape Project, Isle of Man: 5th Report 1999*. Bournemouth Univ School of Conservation Sciences Research Report **7**, 45-53. Bournemouth and Douglas: Manx Natural Heritage

Doonan, R and Hunt, A 1999 'Assessing the research potential for prehistoric mining and metallurgy on the Isle of Man' in T Darvill (ed) 1999, *Billown Neolithic Landscape Project, Isle of Man: 5th Report 1999*. Bournemouth Univ School of Conservation Sciences Research Report **7**, 64-9. Bournemouth and Douglas: Manx Natural Heritage

Douch, H L 1979 *East Wheal Rose: The History of Cornwall's Greatest Lead Mine*. Truro: Barton (2nd reprint)

Down, C G 1980 *The Manganese Mines of North Wales*. British Mining Monograph **14**

Down, C G and Warrington, A J 1971 *The History of the Somerset Coalfield*. Newton Abbot: David and Charles

Doyle, P, Hughes, T and Thomas, I A (eds) 2008 *England's heritage in stone*. English Stone Forum

Duddon Valley Local History Group 2009 *Ring Cairns to Reservoirs*. Kirkby in Furness: BPR

Duff, P M D, and Smith, A J 1992 *Geology of England and Wales.* London: Geological Society of London

Dungworth, D 2011 *Examination of the metalworking debris from the 1939 excavations at Trevelgue Head, Cornwall*. English Heritage Research Report

Dungworth, D and Paynter, S (eds) 2006 *Science for Historic Industries Guidelines for the investigation of 17th - to 19th-century industries*. Swindon: English Heritage

Dunham, K C 1990 *Geology of the Northern Pennine Orefield: Volume 1 – Tyne to Stainmore*. London: HMSO (2nd edition)

Dunham, K C and Dines, H G 1945 *Barium Minerals in England and Wales, Wartime pamphlet* **46.** London: HMSO

Dunham, K C and Wilson, A A 1985 *Geology of the Northern Pennine Orefield: Volume 2 – Stainmore to Craven*. London: HMSO

Dunham, K C and Wilson, A A 1985 'The Richmond copper mines' in *Geology of the Northern Pennine Orefield: Volume 2 Stainmore to Craven. Memoir of the British Geological Survey*. London: HMSO, 155-162

Dunn, C 1997 *Ham Hill, Somerset. An archaeological survey.* RCHME AI Report

Dunn, P V 2004 *The Stoneycombe Story: 150 years of quarrying at Stoneycombe.* Aggregate Industries Ltd

Dunn, R and Smailes, J 2011 *Steetley: Dolomite Volume 1: Dolomite and seawater operations in the North East of England.* Hartlepool: Connoisseur Crafts

Durant, D N and Riden, P (eds) 1980 The *building of Hardwick Hall, part 1: Old Hall 1587-91 Derbyshire Record Soc* **4**

Durant, D N and Riden, P (eds) 1984 *The building of Hardwick Hall, part 2: New Hall 1591-98 Derbys Record Soc* **9**

Dutton, L and Fasham, P 1994 'Prehistoric Copper Mining on the Great Orme, Llandudno, Gwynnedd' *Proc Prehistoric Soc* **60**, 245–86

Drury, P J 1981 'The production of brick and tile in medieval England' in D W Crossley (ed) *Medieval Industry*. CBA Research Report **40**, 126-42

DTRG 1993 'Fieldwork and Survey at Wheal Fortune Mine' *DTRG Newsletter* **5**, 5-8

DTRG 1996 'Survey of Tin Streamworks in the Ruddycleave Valley' *DTRG Newsletter* **11**, 2, 6-7

DTRG 2003 'Greena Ball Streamwork' *DTRG Newsletter* **24**, 5-10

Durrance, E N and Laming, D J C (eds) 1982 *The Geology of Devon*. Exeter: University Press

Earl, B 1968 *Cornish Mining*. Truro: Barton

Earl, B 1983 'Arsenic Winning and Refining Methods in the West of England' *J Trevithick Soc* **10**, 9-29

Earl, B and Tylecote, R F 1988 'East Cornwall Lead-Silver Smelter at Wheal Langford, Callington' *J Trevithick Soc* **15**, 36-42

Earle, J B F 1971 *A Century of Road Materials: The history of the Roadstone Division of Tarmac Ltd*. Oxford: Basil Blackwell

Earle, J B F 1974 *Black Top - A History of the British Flexible Roads Industry*. Oxford: Basil Blackwell

Eastwood, I and Wild, M 1986 'Industrial Archaeological Geochemical Prospecting (IAGP): A Scientific Aid to the Study of Industrial History' *Hallamshire Historian* **1.1** 17-22

Eaton, T 2000 *Plundering the Past: Roman Stonework in Medieval Britain*. Stroud: Tempus

Eckel, E C 1922 *Cements, limes and plasters. Their materials, manufacture and production*. New York: John Wiley & Sons(2nd edition)

Edmonds, M 2004 *The Langdales – Landscape and Prehistory in a Lakeland Valley*. Stroud: Tempus

Edwards, K C 1966 'Alabaster Working' In K C Edwards (ed) *Nottingham and Its Region*. Nottingham: The British Association, 231-235

Edwards, K 2005 *The Brereton Collieries 1791-1960*. CCMHS

Edwards, R A 2011 *Devon's Non-Metal Mines. Discovering Devon's Slate, Culm, Whetstone, Beer Stone, Ball Clay and Lignite Mines*. Tiverton: Halsgrove

Edwards, K and Warburton, G 2006 *Lea Hall Colliery 1948 – 1990*. CCMHS report

Edwards, R A 2011 *Devon's Non-Metal Mines*. Wellington: Halsgrove

Ehrenreich, R M 1985 *Trade Technology and the Ironworking Community in the Iron Age of Southern Britain*. Oxford: BAR British Series 144

Elliott, L, Brown, J and Howard, A J 1995 *Aston Hill and Hicken's Bridge, Aston-upon-Trent, Derbyshire: An archaeological assessment*. Unpublished report held in the Derbyshire HER

Ellis, N 1995 *South Yorkshire Collieries in Old Picture Postcards*. Nottingham: Reflections

Ellis, N 2002 *West Yorkshire Collieries on Old Picture Postcards*. Nottingham: Reflections

Ellis, P (ed) 2000 *The Roman Macellum at Wroxeter*. Swindon: English Heritage

Ellis, S E 1969 *The Petrography and Provenance of Anglo-Saxon and Medieval English Honestones, with Notes on Some Other Hones*. London: Bull Minerology, British Museum 2.3

Emery, N 1992 *The Coalminers of Durham*. Alan Sutton Encyclopedia Britannica *Evaporite*. [Web document] www.britannica.com/EBchecked/topic/197000/evaporite [accessed 15 October 2012]

English Heritage 1991 *Exploring our Past: strategies for the archaeology of England*. London: HBMC

English Heritage 1998 *Frameworks for our past: a review of research frameworks, strategies and perceptions*. London: English Heritage

English Heritage 2007 *Understanding the Archaeology of Landscapes: A Guide to Recording Practice*. Swindon: English Heritage

English Heritage 2008a Mineral Extraction and the Historic Environment [PDF document] www.english-heritage.org.uk/publications/mineral-extraction-and-historic-environment/mineral-extraction.pdf [accessed 31 January 2015]

English Heritage 2008b *Geophysical Survey in Archaeological Field Evaluation*. Swindon: English Heritage (2nd edition)

English Heritage 2010 *Bletchley and Fenny Stratford Historic Town Assessment Report* (draft). [PDF file] www.buckscc.gov.uk/media/1280387/bletchley_consultation_report_draftv2.pdf [accessed 5 March 2012]

English Heritage 2011 *Archaeological Evidence for Glassworking: Guidelines for Best Practice*. Swindon: English Heritage

English Heritage 2013 *Strategy for Developing Research Resources*, [PDF document] www.english-heritage.org.uk/content/imported-docs/a-e/eh-strategy-developing-research-resources.pdf [accessed 31 Jan 2015]

English Heritage (nd) Pastscape, Pleasington Alum Works [Web document] www.pastscape.org.uk/hob.aspx?hob_id=1195251&sort=4&search=all&criteria=pleasington&rational=q&recordsperpage=10 [accessed 2 February 2014]

Evans, C J, Jenks, W E and White, R H 1999 'Roman Pottery Kilns at Meole Brace (Pulley) Shropshire' *Trans Shropshire Archaeol and Hist Soc* **74**, 1-27

Evans, W B 1970 'The Triassic salt deposits of north-western England' *Quarterly J Geological Soc London* **126.1-2**, 103-123

Eve, D and Stead, P 1998 *The limeburning industry in Kent – Results of a Sites and Monuments Record Enhancement Project 1997-8*. Heritage Conservation Group, Kent County Planning Department

Everson, P L, Taylor, C C and Dunn, C J 1991 *Change and Continuity: Rural Settlement in North-West Lincolnshire*. London: HMSO

Fairbairn, R A 1992 'Alston Moor Hushes' *British Mining Memoirs* **45**, 17-27

Fairbairn, R A 1993 *The Mines of Alston Moor*. British Mining Monograph **47**

Fairbairn, R A 1994 'Bales of Alston Moor, South Northumberland and Weardale' *British Mining Memoirs* **50**, 93-99

Fairbairn, R A 1995 *Lead Mine Waggons*. British Mining Monograph **54**

Fairbairn, R A 1996 *Weardale Mines*. British Mining Monograph **56**

Fairbairn, R A 1998 'A Lead Smelting Site at Haltwhistle Hill, Allendale' *British Mining Memoirs* **61**, 20-1

Fairbairn, R A 2000 *Allendale, Tynedale and Derwent Mines*. British Mining Monograph **65**

Fairbairn, R A 2002 'The Mechanism of Hushing as Used in the North Pennines' *British Mining Memoirs* **41**, 41-58

Fairbairn, R A 2005 *The Mines of Upper Teesdale*. British Mining Monograph **77**

Fairbairn, R A 2007 'A Tenth Century Lead Smelting Site in West Allendale' *British Mining Memoirs* **83**, 47-51

Fanning, G 2001 *Oldham Coal*. British Mining Monograph **68**

Farey, J 1811 *A General View of the Agriculture and Minerals of Derbyshire*. London: Board of Agriculture. (Reprinted by PDMHS, Matlock, in 1989)

Fawn, A J, Evans, K A, McMaster, I and Davies, G M R (eds) 1990 *The Red Hills of Essex: saltmaking in antiquity.* Colchester: CAG

Fell, A 1908 *The Early Iron Industry of Furness and District.* Ulverston: Hume Kitchin (reprinted 1968, London: Frank Cass)

Fenn, R W D 2009 *The Bardon Hill Quarries - I 1858-1918*. Aggregate Industries Ltd report

Ferguson, H T 1873 'On the Mechanical Appliances used for Dressing Tin and Copper Ores in Cornwall' *Proc Institution of Mechanical Engineers* **24**, 119-52

Ferguson, J 1996 'The Copper Slag Blocks of Hayle, Cornwall: Remains of a late 18th-century industry' *Mining History* **13.2**, 104-8

Ferguson, J and Thurlow, C 2005 *Cornish brick making and brick buildings*. St Austell: Cornish Hillside

Field, D 1994 'The Neolithic Industrial Landscape at Cissbury, Sussex' *Bull PDMHS* **12.3**, 22-5

Fielding, A P 2005 'The Lion Salt Works Project' In A M Fielding and A P Fielding (eds) *Salt Works and Salinas*. Lion Salt Works Trust Monograph Series, Research Report **2**, 59-68

Fielding, A M and Fielding, A P 2006 *The Salt Industry*. Oxford: Shire Books

Finberg, H P R 1949 'The Stannary of Tavistock' *Rep Trans Devonshire Ass* **81**, 155-84

Finberg, H P R 1950 'An unrecorded Stannary Parliament' *Rep Trans Devonshire Ass* **82**, 295-310

Fincham, G 2004 *Durobrivae: A Roman town between Fen and upland*. Stroud: Tempus

Firman, R J 1964 'Gypsum in Nottinghamshire' *Bull PDMHS* **2.4**, 189-203

Firman, R J 1984 'A Geological Approach to the History of English Alabaster' *Mercian Geologist* **9.3**, 161-78

Firman, R J 1989a 'Alabaster update' *Mercian Geologist* **12.1**, 63-70

Firman, R J 1989b 'A tale of two excursions: geological, historical and environmental aspects of gypsum in Derbyshire and Staffordshire' *Mercian Geologist* **12.1**, 49-55

Fitzgerald, R 2002 'Annular spoil heaps at Thorpe Hesley' *Archaeology in South Yorkshire* **11**, 78-80

Fitzgerald, R 2011 'The Hawton Gypsum Mill and Developments in 19th-Century Grinding Technology' *Industrial Archaeology Review* **33.2**, 122-41

Fletcher, I 1877 'The Archaeology of the West Coal Trade' *Trans Cumberland and Westmorland Antiq and Archaeol Soc* (Old Series) **3**, 266-313

Fletcher, M 2000 *The Ferro Ceramic Mine and Shaugh Brickworks, Meavy, Devon*. EHAI Report Series **AI/8/2000**

Fletcher, M, Newman, P and Probert, S 1997a *Meldon Industrial Landscape, Okehampton, Devon. An archaeological survey.* RCHME AI report

Fletcher, M, Newman, P and Probert, S 1997b *Roman Lode, Burcombe, Simonsbath, Exmoor*. RCHME AI report

Flinn, M W 1985 *The History of the British Coal Industry Volume 2: 1700-1830 The Industrial Revolution*. Oxford: University Press

Fluck, P 2014 'Archaeology of mines and metals: an historiographic review' in J Silvertant (ed) *Research and preservation of ancient mining areas*. Trento/Valkenburg aan de Geul: Institute Europa Subterranea, 70-87

Ford, T D 2001a 'The geology of the Matlock mines: a review' *Mining History: Bull PDMHS* **14.6,** 1-34

Ford, T D 2001b 'Derbyshire wad and umber' *Mining History* **14.5**, 39-45

Ford, T D 2002 'Calcite Mining in the Peak District' *Mining History: Bull PDMHS* **15.1**, 29-37

Ford, T D 2003 'Iron Mining in the Peak District' *Mining History: Bull PDMHS* **15.3**, 8-14

Ford, T D 2005a *Derbyshire Blue John*. Ashbourne: Ashbourne Editions

Ford, T D 2005b 'The geology of the Wirksworth mines: a review' *Mining History: Bull PDMHS* **16.2**, 1-42

Ford, T D 2006 'Manganese Mining in the Peak District' *Mercian Geologist* **16.3**, 200-02

Ford, T D 2008 'The geological setting of the lead mines in the Lathkill amd Wye Valley area, Derbyshire' *Mining History: Bull PDMHS* **17.2**, 1-46

Ford, T D 2010 'The geological setting of the lead mines in the northern part of the White Peak, Derbyshire' *Mining History: Bull PDMHS* **17.5**, 1-48

Ford, T D 2012 'The geological setting of the lead mines of the Hucklow, Eyam, Stoney Middleton and Longstone Edge area, Derbyshire' *Mining History: Bull PDMHS* **18.3**, 1-22

Ford, T D and Jones, J A 2007 'The geological setting of the mineral deposits at Brassington and Carsington, Derbyshire' *Mining History: Bull PDMHS* **16.5**, 1-23

Ford, T D and Rieuwerts, J H 2000 *Lead Mining in the Peak District*. Ashbourne: Landmark

Ford, T D and Willies, L (eds) 1994 *Mining Before Powder. Papers presented at the Georgius Agricola 500th Anniversary Conference. Mining History: Bull PDMHS* **12.3**

Fordham, D 2009a *Bentley Colliery and Bentley New Village*. Doncaster: Fedj-el-Adoum

Fordham, D 2009b *Brodworth Colliery, Woodlands and Highfields*. Doncaster: Fedj-el-Adoum

Fordham, D 2009c *Askern Main Colliery and Instonville*. Doncaster: Fedj-el-Adoum

Forster, W 1821 *A Treatise on a Section of the Strata from Newcastle-upon-Tyne to the Mountain of Cross Fell in Cumberland*. Alston: John Pattison (2nd edition)

Fortey, N J, Ingham, J D, Skilton, B R H, Young, B and Shepherd, T J 1984 'Antimony mineralisation at Wet Swine Gill, Caldbeck Fells, Cumbria' *Proc Yorkshire Geol Soc* **45**, 59-65

Forward, E A (trans) 1971 C Von Oeynhausen and H Von Dechen *Railways in England 1826 and 1827*. Cambridge: Newcomen Society

Fox, A 1973 *South West England*. Newton Abbot: David and Charles

Fox, A 1996 'Tin Ingots from Bigbury Bay, South Devon' *Proc Devon Archaeol Soc* **53**, 11

Fox, H 1994 'Medieval Dartmoor as seen through the Account Rolls' *Proc Devon Archaeol Soc* **52**, 149-71

Fox-Strangways, C 1903 *The geology of the country near Leicester*, London: Geological Survey of Great Britain Sheet156

Fradley, M 2009 *Charterhouse, Somerset: The Development of a Romano-British Mining Settlement and Associated Landscape*. EH Research Report **9/2009**

Francis, A J 19977 *The Cement Industry 1796-1914, A History*. Newton Abbot: David and Charles

Francis, P, Price, J, Yapp, K and Wall, T 2000 *Never on a Sunday*. Bucknell: Scenesetters

Franks, A 2000 *Nottinghamshire Collieries on Old Picture Postcards*. Nottingham

Fullilove, K and Dennis, M 2006 *Ironworking in Norfolk*. Norfolk Heritage Explorer, [Web document] www.heritage.norfolk.gov.uk/record-details?tnf857-Ironworking-in-://norfolk-%28article%29 [accessed 21 December 2012]

Fyfe, R 2003 *Sherracombe Ford and North Twitchen Springs, Exmoor: Analysis of Pollen and Microscopic Charcoal from Mires Associated with Sherracombe Ford*. Unpublished report

Fyfe, R 2009 *Roman Lode, Burcombe, Exmoor, North Devon: Pollen Analysis of Blanket Peat Deposits*. Unpublished report

Galbraith, V H 1920 'Royal Charters to Winchester' *English Historical Reveiw* **35**, 382-400

Gale, D 1989 'Evidence of ancient copper mining at Engine Vein, Alderley Edge' *Bull PDMHS* **10.5**, 266-73

Gale, D 1993 'Prehistoric Mining at Alderley Edge' *Cheshire Past*, 6-7

Gale, D 1995 *Stone tools employed in prehistoric metal mining*. Unpublished PhD thesis, University of Bradford

Gallagher, M J, Stone, P, Kemp, A E S, Hills, M G, Jones, R C, Smith, R T, Peachey, D Vickers, B P, Parker, M E, Rollin, K E and Skilton, B R H 1983 *Stratabound arsenic and vein antimony mineralisation in Silurian greywackes at Glendinning, south Scotland*. London: BGS Mineral Reconnaissance Programme **59**

Gallois, R 2012 'The Norfolk oil-shale rush, 1916-1921' *Proceedings of the Geologists' Association* **123.1**, 64-73

Garner, A, Housley, R and Prag, J 1994 'The Alderley Edge Shovel: an Epic in Three Acts' *Current Archaeology* **137**, 172-5

Geddes, R S 1975 *Burlington blue-grey: A history of the slate quarries of Kirby-in-Furness*. Published privately

George, P K 1993 'The Continuing Decline of Coal Mining in Nottinghamshire and the East Midlands' *Trent Geographer* **14**, 31-46

Gerrard, G A M 1983 *The Excavations of a Medieval Tin Works at West Colliford, St Neots parish, Cornwall*. Unpublished MA thesis, University of Wales, Lampeter

Gerrard, G A M 1986 *The Early Cornish Tin Industry: an archaeological and historical survey*. Unpublished PhD thesis, University of Wales, Lampeter

Gerrard, G A M 1987 'Streamworking in Medieval Cornwall' *J Trevithick Soc* **14**, 7-31

Gerrard, S 1985 'Retallack: a Late Medieval Tin Mining Complex in the Parish of Constantine and its Cornish Context' *Cornish Archaeol* **24**, 175-82

Gerrard, S 1992 'The Beckamoor Combe Streamwork Survey' *DTRG Newsletter* **3**, 6-8

Gerrard, S 1989 'The Medieval and Early Modern Cornish Stamping Mill' *Industrial Archaeology Review* **12.1**, 9-19

Gerrard, S 1994 'The Dartmoor Tin Industry: an Archaeological Perspective' *Proc Devon Archaeol Soc* **52**, 173-98

Gerrard, S 1996 'The Early South-Western Tin Industry: An Archaeological View' *Mining History* **13.2**, 67-83

Gerrard, S 1997 *Lydford Woods Alluvial Tin Streamwork: A report on fieldwork carried out during 1994-5*. Published privately

Gerrard, S 2000 *The Early British Tin Industry*. Gloucester: Tempus

Gibbs, F W 1950 'The Rise of the Tinplate Industry' *Annals of Science* **6.4**, 390-403

Gibson, D and Knight, M (forthcoming) *Bradley Fen, Cambridgeshire*

Gibson-Hill, J 1980 'Cylindrical shaft furnaces of the early Wealden Iron Industry: circa 100 BC to AD300' *Historical Metallurgy* **14.1**, 21-7

Giffard, H P W 1938 'The Former Cannel Oil Industry in North Wales and Staffordshire' *Oil Shale & Cannel Coal*. Proceedings of a Conference held in Scotland. Institute of Petroleum, 78-95

Gill, J (ed) 2001 *Durham Collieries*. Durham: Durham County Record Office

Gill, M C 1986 'An assessment of lead smelting processes and the use of XRF for the analysis of resulting slags' *Historical Metallurgy* **20.2**, 63-78

Gill, M C 1987 *The Yorkshire and Lancashire Lead Mines*. British Mining Monograph **33**

Gill, M C 1988a 'Mechanisation at the Grassington Lead Mines' *Industrial Archaeology Review* **11.1**

Gill, M C 1988b 'Yorkshire Lead Mining before 1700' *British Mining Memoirs* **37**, 46-62

Gill, M C 1989 Customary Mining Law in Yorkshire. A paper presented to the International Mining History Conference, Bochum, Germany, September 1989

Gill, M C 1992 'Yorkshire Smelting Mills Part 1. The Northern Dales' *British Mining Memoirs* **45**, 111-50

Gill, M C 1993a *The Grassington Mines*. British Mining Monograph **46**

Gill, M C 1993b 'Yorkshire Smelting Mills Part 2. The Southern Dales' *British Mining Memoirs* **48**, 132-51

Gill, M C 1993c *Lead Mining Landscapes of the Yorkshire Dales*. Unpublished report

Gill, M C 1993d *Designated Mining Landscapes in the Yorkshire Dales – Mining Related Landscapes*. Unpublished report to accompany the 1993 mapping

Gill, M C 1994 *The Wharfedale Mines*. British Mining Monograph **49**

Gill, M C 1998 *The Greenhow Mines*. British Mining Monograph **60**

Gill, M C 2000a 'Steam and water pressure engines on Yorkshire Dales Mines' *British Mining Memoirs* **67**, 70-98

Gill, M C 2000b 'Yorkshire Smelting Mills Part 3. Corrigenda' *British Mining Memoirs* **67**, 108-19

Gill, M C 2000c 'Recreating Mining Landscapes' *British Mining Memoirs* **67**, 44-51

Gill, M C 2001 *Swaledale: Its Mines and Smelt Mills*. Ashbourne: Landmark

Gill, M C 2004a *Swaledale, its Mines and Smelt Mills*. Ashbourne: Landmark (reprint)

Gill, M C 2004b 'Small Streams of Water – Grassington Moor' in P Claughton 2004 (ed) 16-20

Gill, M C 2004c *Keighley Coal*. British Mining Monograph **74**

Gill, M C 2007 'Towards a chronology for Britain's coal industry from 1854 onwards' *British Mining Memoirs* **83**, 64-75

Gill, M C 2008 'Great Dales Coalfield, Eastern Areas' *British Mining Memoirs* **86**, 68-108

Gill, M C 2009 'The Iron Man Coal Cutter' *British Mining Memoirs* **88**,116-23

Gill, M C 2010a 'The North Yorkshire Moors Coalfields (Yorkshire's Other Forgotten Coalfields)' *Mining History: Bull PDMHS* **17.6**, 19-31

Gill, M C 2010b 'John Barratt and the Grassington Mines 1818-1834' *Mining History: Bull PDMHS* **17.6**, 10-16

Gill, M C and Burt, R 2003 *The Mines of Yorkshire (Metalliferous and associated minerals)* British Mining Monograph **72**

Gill, M C and McNeil, J H 1977 'A Report on the Excavations at the Chimney Shaft, Cockhill Mine' *British Mining Memoirs* **5**, 54-6

Gill, M C and Squirrell, M 2014 'Malham Mines' *British Mining* **97**

Gimpel, J 1977 *The medieval machine: the industrial revolution of the Middle ages*. USA: Penguin

Glasscock, R E 1976 'England *circa* 1334' in H C Darby (ed) *A New Historical Geography of England Before 1600*. 136-85

Goddard, J, Hart, N, Marley, R, Smisson, R and Tofts, S 2009 *A Study of Velvet Bottom and its Dams, Charterhouse on Mendip*. Somerset: CHERT

Good, G L 1987 'An 18th - 19th century limekiln at Water Lane, Temple, Bristol' *Bristol Avon Archaeol* **6**, 66-9 Goodchild, J 2000 *West Yorkshire Coalfield*. Stroud: Tempus

Goodman, K 1978 *Hammerman's Hill; the land, people and industry of the Titterstone Clee Hill area of Shropshire from the 16th to the 18th Centuries*. Unpublished PhD thesis, University of Keele

Goodridge, T C 1964 'Devon Great Consols: a study of Victorian living' *Rep Trans Devonshire Ass* **96**, 228-68

Gossip, J 2000 *Portreath to Poldice Minerals Tramway - Archaeological and Historical Assessment*. Cornwall CC HES Report **2000R047**

Gough, J W 1967 *The Mines of Mendip*. Newton Abbot: David and Charles

Gould, S 1991 *Vobster Breach Colliery*. Unpublished diploma dissertation

Gould, S 1994 'Coke Ovens at Vobster Breach Colliery' *Industrial Archaeology Review* **17.1**, 179-85

Gould, S 1996 ' The Collieries of North Somerset' *Mining History: Bull PDMHS* **13.2**, 16-26

Gould, S 1999 *The Somerset Coalfield*. Somerset Industrial Archaeol Soc Survey **11**

Gould, S 2005 *Coal Mining in Somerset: An Assessment of the surviving Field Remains, Their Significance and Recommendations for Future Management*. Unpublished report

Gould, S and Ayris, I 1995 *Colliery Landscapes; an aerial survey of the deep-mined coal industry in England*. London: English Heritage

Gould, S and Cranstone, D 1993 *Monuments Protection programme: The Coal Industry Step One Report*. Cranstone Consultancy for English Heritage

Grant, A 1983 *North Devon Pottery: the Seventeenth Century*. Exeter: University Press

Grant, D 1985 'The Sixth Duke of Somerset, Thomas Robinson and the Newlands Mines' *Trans Cumberland and Westmorland Antiq and Achaeol Soc* **85**,143-62

Grant, E G 1978 *A Warwickshire Colliery in the Seventeenth Century*. Dugdale Society occasional papers **26**

Gray, G D B 1976 'The South Yorkshire Coalfield' in J Benson and R G Neville (eds) *Studies in the Yorkshire Coal Industry*. Manchester University Press Barnsley: Wharncliffe, 31-44

Gray, T 1987 *The Road to Success – Alfred McAlpine 1935-1985*. London: Park Lane Press

Green, H 1935a 'The Nottinghamshire and Derbyshire Coalfield Before 1850' *J Derbyshire Archaeol and Natural Hist Soc* **56,** 44-60

Green, H 1935b 'The Southern Portion of the Nottinghamshire and Derbyshire Coalfield and the development of Transport Before 1850' *J Derbyshire Archaeol and Natural Hist Soc* **56**, 61-70

Greenwell, A and Elsden, V 1913 *Practical Stone Quarrying*. London: Crosby Lockwood

Greeves, T 1969 'A Mine in the Deancombe Valley' *Rep Trans Devonshire Ass* **101**, 197-201

Greeves, T 1975 'Wheal Prosper - a little-known Dartmoor tin mine' *Plymouth Mineral and Mining Club J* **6.1**, 6-7 and 15

Greeves, T 1976 'Merrivale Bridge Mine, Wheal Fortune and the Staple Tor Sett' *Plymouth Mineral and Mining Club J* **6.3**, 3-5 and 11

Greeves, T 1978 'Wheal Cumpston Tin Mine, Holne, Devon - an historical and archaeological survey' *Rep Trans Devonshire Ass* **110**, 161-71

Greeves, T 1981 *The Devon Tin Industry 1450-1750: an Archaeological and Historical Survey*. Unpublished PhD, thesis, University of Exeter

Greeves, T 1981a 'The archaeological potential of the Devon tin industry' in D W Crossley (ed) *Medieval Industry*. CBA Research Report **40**, 85-95

Greeves, T 1985 'Steeperton Tor Mine, Dartmoor, Devon' *Rep Trans Devonshire Ass* **117**, 101-27

Greeves, T 1986 *Tin Mines and Miners of Dartmoor*. Exeter: Devon Books

Greeves, T 1987 'The Great Courts or Parliaments of the Devon Tinners 1474-1786' *Rep Trans Devonshire Ass* **119**, 145-67

Greeves, T 1992 'Four Devon Stannaries: A Comparative Study of Tinworks in the Sixteenth century' In Gray, T *et al.* (eds) *Tudor and Stuart Devon - The Common Estate and Government*. Exeter: University Press, 39-74

Greeves, T 1994 'Tin Stamping and Smelting at Upper Merrivale, Devon' in Ford and Willies (eds) 1994, 76-80

Greeves, T 1996 'Tin Smelting in Devon in the 18th and 19th Centuries' *Mining History: Bull PDMHS* **13.2**, 84-90

Greeves, T 2002 'A History of Whiteworks Tin Mine Part Two: 1848-1914' *Plymouth Mineral and Mining Club J* **32.2**, 3-6

Greeves, T 2003 'Devon's Earliest Tin Coinage Roll 1302-3' *Rep Trans Devonshire Ass* **135**, 9-29

Greeves, T and Newman, P 2011 *The Great Courts of Devon Tinners 1510 and 1710.* DTRG Occasional Publication **2**

Gregory, R A and Lloyd, D 2003 *The Rossendale Quarrying Industry: Archaeological Assessment Report.* UMAU Report **45**

Gregory, S, Lawton, R and Learmonth, A T A 1953 'The Middle Mersey and the chemical area' in W Smith (ed) *A Scientific Survey of Merseyside.* Liverpool: University Press, 251-267

Griffin, A R 1971 *Mining in the East Midlands, 1550-1947.* London: Frank Cass

Griffin, A R 1972(Feb) 'Brinsley Colliery: A Conflict of Evidence' *Industrial Archaeology,* 28-47

Griffin, A R 1981 *The Nottinghamshire Coalfield 1881-1981*. Moorland

Griffith, F and Weddell, P 1996 'Ironworking in the Blackdown Hills: results of recent survey' *Mining History: Bull PDMHS* **13.2**, 27-34

Grigor-Taylor, W R 1972 'Notes on the Lathkill Gold Mine' 1854-1856' *Bull PDMHS* **5.1**, 43-9

Grimshaw, P N 1985 *Excavators.* Pool: Blandford Press

Grudgings, S 2009 'Coalpit Heath Coalfield: Developments in the eighteenth century' *Bristol Industrial Archaeol Soc J* **42**, 43-56

Grudgings, S 2015 *The History and Archaeology of the Steam Engines of the Coalpit Heath Colliery Company.* SGMRG

Guilbert, G 1996 'The oldest artefact of lead in the Peak: new evidence from Mam Tor' *Mining History* **13.1**, 12-18

Guilbert, G 1994a 'Hammer stones from the Ecton copper mine' *Bull PDMHS* **12.3**, 26-7

Guilbert, G 1994b 'More on the Ecton hammer stones' *Bull PDMHS* **12.4**, 14

Gurney, D A 1978 *Iron Age and Romano-British Salt Production on the Essex coast.* Unpublished BA dissertation, University of Durham

Gurcke, K 1987 'British firebricks in North America' *Historical Metallurgy* **21.1**, 18-24

Guthrie, A 1969 'Excavations of a settlement at Goldherring, Sancreed 1958-61' *Cornish Archaeol* **8**, 5-39

Guy, A and Atkinson, F 2008 *West Durham: the archaeology of industry*. Stroud: Phillimore

Guy, A and Cranstone, D 2001 *Moorhouse Woods, Co. Durham: Assessment of Documentation*. Report by the Cranstone Consultancy for The National Trust

Gwyn, D and Palmer, M (eds) 2005 *Understanding the Workplace. Industrial Archaeology Review* **27.1**

Hackman, G 2014 *Stone to Build London: Portland's Legacy.* Monkton Farleigh: Folly Books

Hair, T H 1844 *A series of views of the collieries in the counties of Northumberland and Durham*. Newcastle-Upon-Tyne: Davis Books (reprinted 1987)

Halkon, P and Millet, M 1999 *Rural Settlement and Industry: Studies in the Iron Age and Roman Archaeology of Lowland East Yorkshire.* Leeds: Yorkshire Archaeological Society

Hall, G 2000 *Mines of the Sixties.* Ludlow: Griffin

Hall, R 2008 'Putting the Iron into the Iron Age' *British Archaeology* **98**, 44-7

Hall, R M S 1981 *The Lee Moor Tramway*. Blandford: Oakwood Press

Hallett, J 1994 *Around Princetown's Quarries: The Tyrwhitt railway trail from Princetown*. Newton Abbot: Orchard

Hamilton Jenkin, A K 1927 *The Cornish Miner*. London : Allen and Unwin

Hamilton Jenkin, A K 1961 *Mines and Miners of Cornwall, Volume 1 St Ives*. Truro Bookshop

Hamilton Jenkin, A K 1962a *Mines and Miners of Cornwall Volume 2 St Agnes to Perranporth*. Truro Bookshop

Hamilton Jenkin, A K 1962b *Mines and Miners of Cornwall, Volume 3 Around Redruth*. Truro Bookshop

Hamilton Jenkin, A K 1962c *Mines and Miners of Cornwall, Volume 4 Penzance to Mounts Bay*. Truro Bookshop

Hamilton Jenkin, A K 1963a *Mines and Miners of Cornwall, Volume 5 Hayle, Gwinear and Gwithian*. Truro Bookshop

Hamilton Jenkin, A K 1963b *Mines and Miners of Cornwall, Volume 6 Around Gwennap*. Truro Bookshop

Hamilton Jenkin, A K 1963c *Mines and Miners of Cornwall, Volume 7 Perranporth to Newquay*. Truro Bookshop

Hamilton Jenkin, A K 1964a *Mines and Miners of Cornwall, Volume 8 Truro to the China Clay District*. Truro Bookshop

Hamilton Jenkin, A K 1964b *Mines and Miners of Cornwall, Volume 9 Padstow, St Column and Bodmin*. Truro Bookshop

Hamilton Jenkin, A K 1965a *Mines and Miners of Cornwall, Volume 10 Camborne and Illogan*. Truro Bookshop

Hamilton Jenkin, A K 1965b *Mines and Miners of Cornwall, Volume 11 Marazion, St Hilary and Breage*. Truro Bookshop

Hamilton Jenkin, A K 1966 *Mines and Miners of Cornwall, Volume 12 Around Liskeard*. Truro Bookshop

Hamilton Jenkin, A K 1967a *Mines and Miners of Cornwall, Volume 13 The Lizard, Falmouth and Mevagissey*. Truro Bookshop

Hamilton Jenkin, A K 1967b *Mines and Miners of Cornwall, Volume 14 St Austell to Saltash*. Truro Bookshop

Hamilton Jenkin, A K 1969 *Mines and Miners of Cornwall, Volume 15 Calstock, Callington and Launceston*. Truro Bookshop

Hamilton Jenkin, A K 1974 *Mines of Devon Volume 1: The Southern Area.* Newton Abbot: David and Charles

Hamilton Jenkin, A K 1981 *Mines of Devon: North and East of Dartmoor.* Exeter: Devon Library Services

Hamilton, J R and Lawrence, J F 2008 *Men and Mining on the Quantocks*. Exmoor Mines Research Group (2nd edition)

Hamilton, K, McDonnell, J G and Schmidt, A 1999 'Assessment of early lead working sites in the Yorkshire Dales by geophysical prospection' *British Mining Memoirs* **63**, 158-64

Hammersley, G 1973 'Technique or Economy?: the Rise and Decline of the Early 18th-century Copper Industry, *c.*1550-1660' *Business History* **15**, 1-31

Hancock, P L (ed) 1983 *The Variscan fold belt in the British Isles*. Bristol: Adam Hilger

Hannaford, H R 2004 *The Stiperstones Hills Archaeological Survey: assessment report and updated research design.* Unpublished report

Hannaford, H R 2006 *The Stiperstones Hills Archaeological Survey: a report for land management purposes.* Unpublished report

Hannaford, H R and Price, G 1995 *Building recording and archaeological monitoring of consolidation works at Snailbeach Lead Mine.* Unpublished report

Hanworth, R and Tomalin, D J 1977 *Brooklands, Weybridge. The excavations of an Iron Age and Medieval site, 1964-65, 1970-71*. Surrey Archaeol Soc Reserve **4**

Hardwick, D and Kemp, K 2009 'Rescue dig at Yate Number 2 Winding Pit' *Bristol Industrial Archaeol Soc J* **42**, 29-42

Harris, A 1970 *Cumberland Iron*. Truro: Bradford Barton

Harris, A 1974 'Colliery settlements in East Cumberland' *Trans Cumberland and Westmorland Antiq and Archaeol Soc* **74**, 118-46

Harris, A P 1990 *Building stone in Norfolk* in Parsons (ed) 1990a, 2007-16

Harris, A L, Holland, C H and Leake, B E (eds) 1979 *The Caledonides of the British Isles reviewed*. Special Publication Geological Society London, No. 8

Harris, H 1966 *The Industrial Archaeology of Dartmoor*. Newton Abbot: David and Charles

Harris, H 1981 'Nineteenth Century Granite Working on Pew Tor and Staple Tor, Western Dartmoor' *Rep Trans Devonshire Ass* **113**, 29-51

Harris, H 2002 *The Haytor Granite Tramway and the Stover Canal*. Newton Abbot: Peninsula

Harris, J R 1964 *The Copper King*. Liverpool: Liverpool University Press

Harris, P M 1977a *Sandstone: Mineral Dossier 17*. MRCC London: HMSO

Harris, P M 1977b *Igneous and Metamorphic Rocks: Mineral Dossier 19*. MRCC London: HMSO

Harris, P M 1982 *Limestone and Dolomite: Mineral Dossier 23*. MRCC London: HMSO

Harris, P M 2003 *Lost Industries of Turton Moor*. Turton Local Hist Soc **24**

Harris, T R 1974 *Dolcoath: Queen of Cornish Mines*. Camborne: Trevithick Society

Harrison, A M, Morigi, A N, Thomas, I A, Down, K E, Linley, K A, Steadman, E J, Williams, N and Lawley, R 2007 *Aggregate supply and demand for sustainable communities*. Keyworth: BGS

Hartley, R F 1994 'Tudor Miners of Coleorton, Leicestershire' in T D Ford, and L Willies (eds) 1994, 91-101

Hatcher, J 1973 *English Tin Production and Trade Before 1550*. Oxford: Clarendon

Hatcher, J 1993 *The History of the British Coal Industry Volume I. Before 1700s – Towards the Age of Coal*. Oxford: Clarendon Press

Hatcher, J and Barker, T C 1974 *A History of British Pewter*. London: Longman

Hawkins, D 2011 *Bath stone quarries*. Bradford on Avon: Folly Books.

Hayes, G 1987 *Collieries in the Manchester Coalfields*. Eindhoven: De Archaeologische Pers

Hayes, R H 1988 'Rosedale West Medieval Ironworkings, Excavations 1974-7' in P R Wilson (ed) *North-East Yorkshire Studies: Archaeological Papers by Raymond H Hayes, MBE, FSA*. Yorkshire Archaeol Soc, 106-21

Hayes, R H and Rutter, J G 1974 *Rosedale Mines and Railway*. SAHS Research Rep **9**

Hayfield, C and Wagner, P 1998 'Use of chalk as a building material in the Yorkshire Wolds' *Vernacular Architecture* **29**, 1-12

Haywood, K M J 2009 *Roman quarrying and stone supply on the periphery: a geological study of first century funerary monuments and monumental architecture*. BAR Series 500. Oxford: Archaeopress

Heanor and District Local History Society 1993 *A History of Mining in the Heanor Area.*

Heath, J 1977 'The Aston-on-Trent Tramway' *Derbyshire Miscellany* **8.2**, 74-75

Heathcote, C 1997 'Surface Remains of the New Venture Lead Mine, Bradwell Moor, Derbyshire' *Mining History: Bull PDMHS* **13.3**, 53-6

Heathcote, C 1997 'Surface Remains of the New Venture Lead Mine, Bradwell Moor, Derbyshire - Part 2' *Mining History: Bull PDMHS* **13.4**, 51-4

Heathcote, C 1998 'Surface Remains of the New Venture Lead Mine, Bradwell Moor, Derbyshire – Part 3' *Mining History: Bull PDMHS* **13.6**, 23-4

Heathcote, C 2002 'Lead Veins within the Coal Mines around Whaley Bridge, New Mills and Bugsworth, Derbyshire' *Mining History: Bull PDMHS* **15.1**

Heathcote, J 1980 'Huglith Mine' *SCMC Journal,* 21-29

Hedley, I 1995 *Craghead Opencast, Edmondsley County Durham: Archaeological Watching Brief for Hutchinsons Mining Ltd.* LUAU report

Heffer, P 1985 *East Pool and Agar: A Cornish Mining Legend.* Redruth: Dyllansow Truran

Hemingway, J E 1974 'Ironstone' in D H Rayner and J E Hemingway (eds) *The Geology and Mineral Resources of Yorkshire*. Yorkshire Geological Society, 329-31

Henesey, A 2004 *Routes to your roots: mapping your mining past*. Wakefield: National Coal Mining Museum for England

Henesey, A 2010 'The Gascoignes and the Garforth miners in the nineteenth century' *British Mining Memoirs* **90**, 74-89

Henstock, A 1999 "T'Owd Mon Wor From Bonsor": The Origins of the Medieval Miner's Effigy in Wirksworth Church' *Mining History: Bull PDMHS* **14.2**, 68-9

Herring, P 1996 *Repairs to the spalling floor of Porthmoina Mill.* CAU unpublished report

Herring, P 2000 *St, Michael's Mount Cornwall: Reports on Archaeological Works, 1995-1998*. Truro: Cornwall County Council.

Herring, P and Thomas, N 1990 *The Archaeology of Kit Hill*. Truro: Cornwall County Council

Herring, P, Sharpe, A, Smith, J R, Giles, C, and Johnson, N 2008 *Bodmin Moor: An archaeological survey, Volume 2: The industrial and post-medieval landscapes*. London: English Heritage

Herring, P and Smith, J R 1991 *The Archaeology of the St Austell China-Clay Area*. Truro: Cornwall County Council

Hewer, R E 1984 'Bannerdale Lead Mine' *British Mining Memoirs* **25**, 26-30

Hewer, R E 1988 *The Kelton and Knockmurton Iron Mine*. British Mining Monograph **36**

Hewitson, C 2015 T*he Open Pan: The Archaeology and History of the Lion Salt Works*. Lion Salt Works Research Report **6**

Higgins, G M and Pickford, R F 1975 *Bath stone: a short history.* Bath: Geology Museum

Highley, D E 1976 'The economic geology of the Weald' *Proc Geologists' Assoc* **86.4** (for 1975), 559-569

Highley, D E 1977 *Silica: Mineral Dossier 18*. MRCC London: HMSO

Highley, D E, Chapman, G R, Warrington, G and Cameron, D G (compilers) 1996 *Industrial Mineral Resources Map of Britain*. BGS (NERC)

Hignett, N H 1935 'Vale Royal: a shrine of Cheshire and English history' *Cheshire Life,* Oct 1935, 7-13

Hill, A 1991 *Coal Mining: A Technological Chronology 1700-1950*. Sheffield: British Mining Supplement

Hill, A 2000 *The History and Development of Colliery Ventilation*. Matlock Bath: PDMHS

Hill, A 2002 *The South Yorkshire Coalfield: A History and Development.* Stroud: Tempus

Hill, A 2011 *Coal: A Chronology For Britain*. British Mining Monograph **94**

Hill, B P and Clemo, G R 1949 'Chemicals' In *Scientific Survey of north-eastern England*. Newcastle upon Tyne: The British Association, 161-70

HMIMQ 1950 *Report 1939-1949*, 5-9

Hockensmith, C D and Ward, O 2007 'Millstones, querns and millstone quarries in the UK: a bibliography' *International Molinology* **74**, 24-31

Hodges, R 1991 *Wall-to-Wall History: The Story of Roystone Grange*. Duckworth and Co.

Hodgkinson, D, Croft A, Hair, N, Elder, S and Scott, I 1997 *North West Water's Forest of Bowland Estate, Lancashire. Archaeological Survey.* LUAU report

Hodgkinson, J 1999 'Romano-British iron production in the Sussex and Kent Weald: a review of current data' *Historical Metallurgy* **33.2**, 68-72

Hodgkinson, J 2008 *The Wealden Iron Industry.* Stroud: The History Press

Hodgkinson, D, Croft, A, Hair, N, Elder, S and Scott, I 1997 *North West Water's Forest of Bowland Estate, Lancashire. Archaeological Survey.* LUAU report

Holbrook, N and Bidwell, P 1991 *Roman Finds from Exeter*. Exeter Archaeology Report **5**. Exeter: University Press

Holgate, R 1995 'Neolithic Flint Mining in Britain' *Archaeologia Polona* **33**

Holland, E G 1986 *Coniston Copper Mines: a history*. Cicerone Lane

Holland, H 1808 *General View of the Agriculture of the County Palatine of Chester*. London: Board of Agriculture

Holley, S 1997 *An Investigation of Limekilns on Exmoor for the Purposes of Conservation.* Unpublished BSc dissertation, University of Bournemouth

Hollingsworth, J P 2010 '*Those dirty miners': A history of the Kent Coalfield.* Catrine: Stenlake

Hollister-Short, G 1994 'The Introduction of Powder' in T D Ford, and L Willies (eds) 1994, 148-9

Holmes, J 1885-86 'The bell pits of old Leeds' *Leeds Mercury Supplement Local Notes and Queries* **331**, Jan 1885 to June 1886, 55-6

Hopkins, H 2009 *RAF West Drayton, Porters Way, London Borough of Hillingdon: An Archaeological Desk-Based Assessment for Inland Homes*. Thames Valley Archaeological Services Ltd [PDF file] www.hillingdon.gov.uk/media/pdf/b/d/archaeology_background_information.pdf [accessed 5 March 2012]

Hopkinson, G G 1959 'The Inland Navigations of the Derbyshire and Nottinghamshire Coalfield, 1777-1856' *J Derbyshire Archaeol and Natural Hist Soc* **79**, 22-41

Hornshaw, T R 1975 *Copper Mining in Middleton Tyas. Northallerton*. North Yorkshire CRO Publications No. 6

Hoskins, W G 1954 *Devon*. Chichester: Phillimore (2003 edition)

Hoskins, W G 1955 *The Making of the English landscape.* London: Hodder and Stoughton

Houghton, F T S 1932 'Saltways' *Trans Birmingham and Warwickshire Archaeol Soc* **54**, 1-17

Houlder, C 1979 The 'Langdale and Scafell Pike axe factory sites: a field survey' in McClough, T H and Cummins, W A (eds) *Stone axe studies Volume 1: archaeological, petrological, experimental and ethnographic***.** CBA Research Report **23**

Howard, A and Tod, P 2001 'The plankwalks at Hawton Quarry' *Mercian Geologist* **15.2**, 75-76

Howard, A S, Warrington, G, Ambrose, K and Rees, J G 2008 *A formational framework for the Mercia Mudstone Group (Triassic) of England and Wales.* British Geological Survey Research Report **RR/08/04**. Keyworth, Nottingham: BGS

Howard, A S, Warrington, G, Carney, J N, Ambrose, K, Young, S R, Pharaoh, T C and Cheney, C S 2009 *Geology of the Nottingham district.* Memoir of the British Geological Survey, Sheet 126. Keyworth, Nottingham: BGS

Howard, B 2000 *The Torbay Paint Company.* Dartmouth History Research Group Paper **27**

Hoyle, J, Butler, L, Tait, G and Wooton, D 2007 *The Scowles and Associated Iron Industry Survey: Project Number 3342, Project Report, Volume 1*, GCCAS [Web document] http://ads.ahds.ac.uk/catalogue/adsdata/arch-771-1/dissemination/pdf/scowles_survey_report/scowles_survey_report.pdf

Hudson, K 1971 *The Fashionable Stone: Limestone in Buildings*. Bath: Adams and Dart

Hudson-Edwards, K A, Macklin, M G, Finlayson, R and Passmore, D G 1999 'Medieval lead pollution in the River Ouse at York, England' *Journal of Archaeological Science* **26**, 809–19

Hughes, S R 2005 *Copperopolis: Landscapes of the Early Industrial Period in Swansea*. RCAHMW

Hughes, T G 1996a *The Grey Slates of the South Pennines: The Industry - Report of a study into potential to re-establish the roofing slate industry in the region, Volume 1*. London: English Heritage

Hughes, T G 1996b *The Grey Slates of the South Pennines : The Quarries and The Slates - Report of a study into potential to re-establish the roofing slate industry in the region, Volume 2.* London: English Heritage

Hughes, T G 2003 'Stone Roofing in England' in C Wood (ed) *Stone Roofing*. English Heritage Research Transactions **9**, 32-127

Hughes, T G 2008 *Vernacular slate and stone roofs in England*, in P Doyle et al. (eds) 2008, 28-42

Hughes, T G, Lott, G K, Poultney, M J, and Cooper, B J 2011 Portland Stone: a nomination for "Global Heritage Stone Resource" from the U K [Web document] www.globalheritagestone.org

Hull, E 1861 *The Coalfields of Great Britain*. Sanford

Hull, E 1872 *Treatise on the Building and Ornamental Stones of Great Britain and Foreign Countries*. London: MacMillan

Hunt, A and Ainsworth, S 2010 *Scordale, Cumbria: The Archaeology of a North Pennine Valley*. EH Research Report **35/2010**

Hunt, A, Pearson, T, Sinton, P, Carter, A, Andrews, D, Beckett, N, Tovey, S and Clowes, M 2004 *Loftus Alum Works, Redcar and Cleveland: an archaeological and historical survey.* EHAI Report Series **AI/02/2004**

Hunt, C J 1970 *The Lead Miners of the Northern Pennines*. Manchester: University Press

Hunt, R 1860 *Mineral Statistics part II* [for 1858]. Memoirs of the Geological Survey. London: HMSO

Hunt, R 1887 *A historical sketch of British mining*. Reprinted 1978 by E P Publishing

Hurst, J D (ed) 1997 *A multi-period salt production site at Droitwich – excavations at Upwich.* CBA Research Report **107**

Hussey, D 2000 *Coastal and River Trade in Pre-Industrial England*. Exeter: University Press

Huxley, B 2002 *100 Years of Clay Winning Machinery: The First 50 Years*. Newcastle-under-Lyme: published privately

Huxley, B 2006 *100 Years of Clay Winning Machinery: Part Two, 1950 and on*. Newcastle-under-Lyme: published privately

Hylton, S 2007 *The Grand Experiment: the Birth of the Railway Age 1820-1845.* Ian Allan Publishing

I A Recordings 2012 Video Archive - *Bricks, Tiles and Pipes* [Web document]www.iarecordings.org/subjidx.html#br[accessed 5 March 2012]

Ingle, C J 1987 'The production and distribution of beehive querns in Cumbria – some initial considerations' *Trans Cumberland and Westmorland Antiq and Archaeol Soc* **87**, 11-17

Instone, E 1995 *Monuments Protection Programme: The Iron Industry, Introduction to Step 3 Site Assessments*. Report for EH

Instone, E and Cranstone, D 1994 *Monuments Protection Programme: Coal, Step 3 assessments.* Report for EH

Ireson, A S 1986 *The Stones of Stamford.* Stamford Development Committee

Isham, K 2000 *Lime Kilns and Limeburners in Cornwall: an introduction*. St Austell: Cornish Hillside

Ixer, R A and Pattrick, R A D (nd) *Copper-Arsenic Ores and Bronze Age Mining and Metallurgy with special reference to the British Isles* [Web document] http://goodprovenance.com/fahlerz.htm [accessed 1 March 2013]

Ixer, R A, Young, B and Stanley, C J 1996 'Bismuth-bearing assemblages from the Northern Pennine Orefield' *Mineralogical Magazine* **60**, 317-24

Jackman, P S 1996 'The history, productivity and mineralogy of Snelston Mine, Ashbourne, Derbyshire'. *Mining History: Bull PDMHS* **13.1**, 19-30

Jackson, D A 1979 'Roman iron working at Bulwick and Gretton' *Northamptonshire Archaeology* **14**, 31-7

Jackson, D A 1981 'Archaeology at an ironstone quarry in the Harringworth-Wakerley area 1968-79' *Northamptonshire Archaeology* **16**, 14-33

Jackson, D 1994-5 'Iron Age and Anglo-Saxon settlements and activity around the Hunsbury Hillfort, Northants' *Northamptonshire Archaeology* **25**, 35-46

Jackson, D A, Biek, L and Dix, B F 1973 'A Roman lime kiln at Weekley, Northants' *Britannia* **4**, 128-40

Jackson, J S 1968 'Bronze Age Copper Mines on Mount Gabriel, West County Cork, Ireland' *Archaeologia Austriaca* **43**, 92-114

Jarratt, T 1997 'Five Buddles Sink - a lost cave rediscovered' *Bristol Exploration Club - Belfry Bulletin* **494**, [Web document] http://www.bec-cave.org.uk/publications-mainmenu-32/19-belfry-bulletin/534-belfry-bulletin-no-494-december-1997.html?start=15 [accessed 17 August 2011]

Jarratt, T 2001 'Stocks's House Shaft: digging into history' *Bristol Exploration Club - Belfry Bulletin* **511**, [Web doc] www.bec-cave.org.uk/publications-mainmenu-32/19-belfry-bulletin/551-belfry-bulletin-no-511-september-2001.html?start=15 [accessed 17 August 2011]

Jecock, M, Dunn, C and Lax, A 2001 *Roughton Gill Mine and Silver Gill Mine, Cumbria*. EHAI Report Series **AI/8/2001**

Jecock, M, Dunn, C, Carter, A and Clowes, C 2003 *The Alum Works and Other Industries at Kettleness, North Yorkshire: An Archaeological and Historical Survey.* EHAI Report Series **AI/24/2003**

Jecock, M 2009, 'A Fading Memory: The North Yorkshire Coastal Alum Industry in the Light of Recent Analytical Field Survey by English Heritage' *Industrial Archaeology Review* **31.1**, 54-73

Jefferson, D P 1993 'Building Stone: the Geological Dimension' *Quarterly Journal of Engineering Geology* **26.4**, 305-20

Jefferys, B and Matthews, R 2008 *The Constance Mary Waterwheel and the Decline Mine, Read.* Report in Lancashire HER

Jenkins, A E 1983 *Everyday Life Industrial History and Dialect: Titterstone Clee Hills*. Published privately

Jenkins, D 1995 'Mynydd Parys Copper Mines' *Archaeology in Wales* **35**, 35–7

Jenkins, P 1995 '*Twenty by Fourteen': a history of the south Wales tinplate industry 1700-1961*. Dyfed: Gomer, Llandysul

Jenkins, P R 2001 *The Elmore Mystery*. Pulborough: Dragonwheel

Jeuda, B S 1999 *The Limestone Quarries of Caldon Low, Part 1*. Tarmac Papers. Tarmac Ltd History Initiative Archive

Jeuda, B S 2000a *The Limestone Quarries of Caldon Low*. Leek: Churnet Valley

Jeuda, B S 2000b *The Limestone Quarries of Caldon Low, Part 2.* Tarmac Papers. Tarmac Ltd History Initiative Archive

Jobey, G 1962 'An Iron Age homestead at West Brandon, Durham' *Archaeologia Aelana* **4.40**, 1-34

John, B 2010 *The Blue Stone Enigma, Stonehenge, Preseli and the Ice Age*. Newport: Greencroft

Johnson, D 2002 *Limestone Industries of the Yorkshire Dales*. Stroud: Tempus

Johnson, D 2006 'Foredale Quarry, Helwith Bridge, a historical and archaeological survey' *British Mining* **80**, 111-34

Johnson, D S 2008 'Excavations of a seventeenth-century lime kiln at Kilnsey, North Yorkshire' *British Mining Memoirs* **86**, 31-46

Johnson, D 2010a *Limestone Industries of the Yorkshire Dales*. Stroud: Amberley (2nd edition)

Johnson, D 2010b *Liming and agriculture in the Central Pennines. The use of lime in land improvement from the late thirteenth century to c.1900.* BAR British Series 525. Oxford: Archaeopress

Johnson, D 2010c 'Hushes, delfs and river stonary: alternative methods of obtaining lime in the gritstone Pennines' *Landscape History* **31**, 37-52

Johnson, D 2013 'Lime burning and the uses of lime in the historic county of Westmorland and along the Pennine edge of Cumberland' *Trans Cumberland and Westmorland Antiq and Archaeol Soc* **3.13**, 191-213

Johnson, L 2009 *Peat extraction in the Yorkshire Dales.* Unpublished report for the NAMHO Research Framework

Johnson, N C 1984 'Wizard's Well Mine, Alderley Edge: early nineteenth century cobalt workings' *Journal of the Derbyshire Caving Club*, September 1984, 17-21

Johnson, R 1953 'An ancient Swanwick coal mine' *Derbyshire Archaeol J* **73**, 114-20

Jones, A et al. (forthcoming) *Excavation of a Bronze Age Burial on Whitehorse Hill Dartmoor.* Oxford: Oxbow

Jones, M 1995 'Ironstone Mining at Tankersley in the Nineteenth Century for Elsecar and Milton Ironworks' in B Elliott (ed) *Aspects of Barnsley* **3**. Barnsley: Wharncliffe, 80-115.

Jones, M H 2006 'The Brendon Hills Industrial Survey, 1993-2005' *Industrial Archaeology Review* **28.2**, 97-106

Jones, M H and Hamilton, J 2010 *Neither here nor there? The mining and transport of iron ore from the Brendon Hills to South Wales 1825 – 1925*. Dulverton: ENPA (2 vols)

Jones, S 1999 'Great Orme Bronze-Age Smelting Site, Llandudno' *Archaeology in Wales* **39**, 79

Jope, E M 1964 'The Saxon Building Stone Industries in South and Midland England' *Medieval Archaeol* **8**, 91-118

Joseph, P 2004 'Wheal Hearle, St Just: History and Archaeology' *British Mining Memoirs* **75**, 7-35

Joseph, P 2006 *Cape Cornwall Mine*. British Mining Monograph **79**

Joseph, P 2010 *Hard Graft: Botallack Mine in the Twentieth Century*. Camborne: Trevithick Society

Joseph, P 2012 'The arsenic industry at Botallack Mine, Cornwall and its archaeology: A story of early 20th century adaptive re-use' *British Mining Memoirs* **93**, 50-73

Juleff, G 1997 *Early Iron-working on Exmoor.* Unpublished report for the ENPA and The National Trust, Holnicote Estate

Juleff, G and Bray, L 2007 'Minerals, metal, colours and landscape: Exmoor's Roman Lode in the Early Bronze Age' *Cambridge Archaeol J* **17**, 285-96

Karloukovski, V and Hounslow, M W 2006 *Report on the Archaeomagnetic Dating of an Iron Smelting Furnace, Sherracombe Ford, Exmoor.* Unpublished report

Keller, P T 1988 'The evidence for ancient quern production at Folkestone: an interim note' *Kent Archaeol Review* **93**, 59-68

Keller, P T 1989a 'The Folkestone Quern Stones' *Current Archaeology* **114**, 236-7

Keller, P T 1989b 'Quern production at Folkestone, south east Kent: an interim note' *Britannia* **20**, 193-200

Kelly, J 1866 'Celtic remains on Dartmoor' *Rep Trans Devonshire Assoc* **4**, 45–8

Kelly, M 2008 *Geology of the Lune and Upper Ribble Coalfields*. British Mining Monograph **85**

Kempe, D R C and Harvey, A P 1983 *The petrology of archaeological artefacts*. Oxford: Clarendon

Kendall, J D 1893 *Iron Ores of Great Britain and Ireland.* London

Kennett, P 2006 *Mining and Quarrying in the Porter Valley: Delving into the Past.* Unpublished report by the Friends of the Porter Valley

Kent Underground Group, 1991 *Kent and East Sussex Underground*. Rainham: Meresborough

Kerr, D 1999 *Shale Oil: Scotland*. Published privately (2nd edn)

Kieller, A, Piggott, S and Wallis, F S 1941 'First report of the Sub-Committee on the petrological identification of stone axes' *Proc Prehistoric Soc* **7**, 50-72

Kiernan, D 1989 *The Derbyshire Lead Industry in the Sixteenth Century*. Chesterfield: Derbyshire Record Society with the PDMHS

Kiernan, D and Van de Noort, R 1992 'Bole smelting in Derbyshire' in L Willies and D Cranstone (eds) 1992, 19-21

Kiernan, D and Crossley, D 1992 'The lead-smelting mills of Derbyshire' *Derbyshire Archaeol J* **112**

King, P W 2001 'Wealden Ironmasters in the Midlands' *Bull Wealden Iron Research Group*, 2nd series, **21**, 20-27

King, P 2005 'The production and consumption of bar iron in early modern England and Wales' *Economic History Review*, **58.1**, 1-33

King, P W 2007 'Black Country Mining before the Industrial Revolution' *Mining History* **16.6**, 42-3

King, P W 2010 'Management, finance and cost control in the Midlands charcoal iron industry' *Accounting, Business & Financial History,* **20.3**, 385-412, [PDF document] www.tandfonline.com/doi/pdf/10.1080/09585206.2010.514410 [accessed 25 Oct 2014]

King, R J 1968 'Mineralization: F Permo-Triassic mineralization' in P C Sylvester-Bradley and T D Ford (eds) *The Geology of the East Midlands*. Leicester: University Press, 123-32

King, R J and Ludlam, B A 1969 'The quest for a lost lead mine in Leicestershire' *Bull PDMHS* **4.1**, 3-28

Kinnunen, K A 1988 'Anthropogenic Decrepitation of Fluid Inclusions in Old Mines of Southern Finland: signs of firesetting' *Current Research.* Geological Survey of Finland Special Paper **10**, 143-5

Kirkham, B 2001 'Iron Age and Roman saltmaking on the Lindsey Coast and Marshland' in T Lane and E L Morris (eds) 2001

Kirkham, L 2004 'Astbury Hydraulic lime works Newbold Cheshire' *Mining History* **15.6**, 68-72

Kirkham, N 1968 *Derbyshire Lead Mining through the Centuries*. Truro: D Bradford Barton

Kitching, D A 1977 *The quarries of the Macclesfield area.* Unpublished typescript, Macclesfield library

Knibbs, K V S 1924 *Lime and magnesia*. London: Ernest Benn

Knifton, D C 1985 *Alfreton: A Case Study of Industrial Change in the Post War Period.* Unpublished BsC dissertation

Knoop, D and Jones, G P 1938 'The English Medieval Quarry' *Economic History Review* **9.1**, 17-37

Knoop, D and Jones, G P 1967 *The mediaeval mason*. Manchester: University Press

Korlin, G 2010 'Luxusgut Blau – Romischer Azuritbergbau in Wallerfangen/Saar' *Der Anschnitt* **62**, 174-88

Lake, R D and Shephard-Thorn, E R 1987 *Geology of the country around Hastings and Dungeness*. Memoir of the British Geological Survey, Sheets 320 and 321. London, HMSO

Lake, R D, Young, B, Wood, C J and Mortimore, R N 1987 *Geology of the country around Lewes*. Memoir of the British Geological Survey, Sheet 319. London, HMSO

Lakin, B, Noble, G and Treseder, G 2011 'Stoping methods in the St Just mines before mechanised drilling' in P Claughton and C Mills (eds) *Mining Perspectives.* Truro: Cornwall CC 42-47

Lambert-Gorwyn, D (nd) 'Nailsea – Excavations at the Elms Colliery' *Popular Archaeol* **7**, 21-33

Lancaster, K J 1989 'Mines and quarries on Baugh Fell' *The Sedbergh Historian* **2.4**, 15-20

Landless, V 1979 'Preesall Salt Mines' *British Mining Memoirs* **11**, 38-43

Lane, H and Hardwick, D 2013 *Celestine (One of the old mineral industries of Yate).* SGMRG

Lane, T 2001 'An Iron Age Saltern at Cowbit Wash, Lincolnshire' in Lane and Morris (eds) 2001

Lane, T and Coles, J (eds) 2002 *'Wet and Dry' - Essays in Honour of David Hall'* LHA Reports Series **5**

Lane, T and Morris, E L (eds) 2001 *A Millennium of Saltmaking – Prehistoric and Roman salt production in the Fens*. LHA Report Series **4**

Langton, H M 1928 'Mineral Black' *The Industrial Chemist* (Aug 1928), 3-6

Lawson-Jones, A 1998 *Wheal Buller - Additional Archaeological Survey of Davey's Shaft and Whitford's Shaft.* Cornwall CC HES Report **1998R004**

Lax, A and Maxwell, R 1998 'The Seathwaite Connection, The Archaeological Remains' *National Trust Annual Archaeol Review* 1998-9, 20-2

LUAU 2000 *Nidderdale AONB North Yorkshire Archaeological Survey Report.* [PDF Document] http://archaeologydataservice.ac.uk/archiveDS/archiveDownload?t=arch-472-1/dissemination/pdf/naas_report_cover.pdf [accessed 03 February 2014]

Leach, J 1992 *Coal Mining around Whaley Bridge*. Matlock: Derbyshire Library Service

Leach, J 1995 'Burning lime in Derbyshire pie kilns' *Industrial Archaeology Review* **17.2**, 145-58

Leach, J 1996a 'Coal mining around Quarnford' *Staffordshire Studies* **8**, 66-96

Leach, R 1978 *An Investigation into the use of Purbeck Marble in Medieval England.* Published privately (2nd edition)

Lead, P 1979 *The Caldon Canal and Tramroads*. Usk: Oakwood Press

Lee, G 2006 'Industrial Archaeology in the North York Moors National Park: Recent Work and Research' *Industrial Archaeology Review* **28.2**, 78-85

LeGear, R F 2009 *C N Kidd's Chalk Mine at Shepherds Lane, Dartford*. Kent Archaeol Soc [PDF document] www.kentarchaeology.ac/authors/kidd %27scmdartford.pdf [accessed 18 December 2011]

Lethbridge, T C and Tebbutt, C F 1935 'Ancient limekilns at Great Paxton, Cambridgeshire, and their Saxon church' *Proc Cambridgeshire Antiq Soc* **35**, 95-105

Lewis, A 1990 'Underground exploration of the Great Orme Copper Mines' in P Crew and S Crew (eds) 1990, 5–10

Lewis, A 1994 'Bronze Age Mines of the Great Orme' *Bull PDMHS* **12.3**, 31-6

Lewis, A 1996 *Prehistoric Mining at the Great Orme: Criteria for the identification of early mining.* Unpublished MPhil, thesis, University of Wales, Bangor

Lewis, G R 1908 *The Stannaries - A Study of the Medieval Tin Miners of Cornwall and Devon*. Truro: Barton (published1965)

Lewis, M J T 1970 *Early Wooden Railways*. London: Routledge and Kegan Paul

Lewis, W J 1967 *Lead Mining in Wales*. Cardiff: University of Wales

L'Hour, M 1987 'Un Site Sous-marin sur la cote d'Armorique: l'epave de Ploumanac'h' *Revue Archeologique de l'Ouest* **4,** 113-31

Linton, D (nd) *Merioneth Manganese*. [Web document] www.hendrecoed.org.uk/merioneth-manganese [accessed 4 February 2013]

Ling, R and Courtney, T 1981 'Excavations [of a lead-working settlement] at Carsington, 1979-80' *Derbyshire Archaeol J* **101**, 58-87

Linsley, S M 1992 'The Road past Killhope and some other Orefield Turnpikes' in B Chambers (ed) *Men, Mines and Minerals of the North Pennines.* Killhope: Friends of Killhope

Littler, A 1990 *Sand and Gravel Production*. Nottingham: The Institute of Quarrying

Longworth, I H 1996 *Excavations at Grimes Graves, Norfolk, 1972-1976 - Fasc. 5: Mining in the deeper mines*. London : British Museum

Lord, F (ed) 2011 *The stabilisation of Combe Down Stone Mines: The saving of a village*. Bath: Bath and North-East Somerset Council

Lorigan, C 2007 *Delabole: the history of the Slate Quarry and the making of the village community*. Reading: Pengelly Press

Lorrimer, P (compiler) 2011 *Hollowed Ground: The Combe Down Stone Mines, Bath.* (DVD) Bath: Bath and North East Somerset Council, Oxford Archaeology and Homes and Communities Agency

Lott, G K, Sobey, R A, Warrington, G and Whittaker, A 1982 'The Mercia Mudstone Group (Triassic) in the western Wessex Basin' *Proc Ussher Soc* **5.3**, 340-346

Lott, G 2001 'Geology and building stones in the East Midlands' *Mercian Geologist* **15.2**, 97-122

Lott, G 2008 'The development of the Victorian Stone industry' in Doyle et al. (eds), 44-57

Lowther, A W G 1946 'Early Medieval Iron Key from Leatherhead' *Surrey Archaeological Collections* **50**, 9-46

Lymm 2012 *Early Industries in Lymm*. [Web document] http://lymm.com/about/history-of-lymm/Lymm-Industries [accessed 16 December 2012]

Lysons, D and Lysons, S 1810 *Magna Britannia 2: Chester.* London: Cadell

Lysons, D and Lysons, S 1814 *Magna Britannia 3: Cornwall.* London: Cadell

Lysons, D and Lysons, S 1816 *Magna Britannia 4: Cumberland*. London: Cadell

Lysons, S and Lysons, D 1822 *Magna Britannia 6: Devonshire* (2 vols). London: Cadell

Mackay and Schellmann (consultants) and White, J 1970 *Sand working in Cheshire*. Report for Cheshire CC

Macmillen, N 2009 *A History of the Fuller's Earth Mining Industry around Bath.* Lyndey: Lightmoor Press

Malaws, B 1997 'Process Recording at Industrial Sites' *Industrial Archaeology Review* **19**, 75-98

Male, K O 1958a 'The Growth of Population and Industry 1801-1951' in D Sylvester and G Nulty (eds) *The Historical Atlas of Cheshire*. Chester: Cheshire Community Council, 43-49

Male, K O 1958b 'The Growth of the Salt Industry' In D Sylvester and G Nulty (eds) *The Historical Atlas of Cheshire*. Chester: Cheshire Community Council, 60-62

Malham, A, McDonnell, J G, Aylett, J and Higgs, E 2002 'Tin smelting slags from Crift Farm, Cornwall and the effect of changing technology on slag composition' *Historical Metallurgy* **36**, 84-94

Manchester, M 2000 *Survey of East Castle limekilns near Annfield Plain, County Durham.* Unpublished MA Student project in HER

Manning, D A C 1995 'Cement and Plaster' in D A C Manning (ed) *Introduction to Industrial Minerals*. London: Chapman and Hall, 141-58

Manning, W H 1968 'The Dolaucothi Gold Mines' *Antiquity* **42**, 299-303

Margary, I D 1955 *Roman roads in Britain*. London: John Baker

Marshall, G 1993 *An archaeological assessment of the Loftus Alum Quarry, Cleveland.* Unpublished report for the National Trust

Marshall, G 1994 'Saltwick Alum Works, an Archaeological Interpretation' *Scarborough Archaeol Hist Soc Research Report* **11**

Marshall, G 1995 'Redressing the balance – An Archaeological Evaluation of North Yorkshire's Coastal Alum Industry' *Industrial Archaeology* **18.1**, 39-62

Martell, H M 1999 'Researching Mining History in the UK' *British Mining Memoirs* **63**, 147-57

Martell, H M and Gill, M C 1990 'Ore-Hearth Smelting (Voyage Metallurgique en Angleterre)' *British Mining Memoirs* **41**, 22-36

Martin, R 1997 'Some Sussex Limekilns' *Sussex Industrial History* **27**, 34-39

Mason, H J 1978 *Flint, The Versatile Stone: Flint as a building material and industrial product.* Ely: Providence Press

Mathews, J and Crocker, A 1987 'Barber Fields Coal Drift Workings, Ringinglow, Sheffield' *Bull PDMHS* **10.1**, 79-80

Maxfield, V 1991 'Tiverton Roman fort (Bolham)' *Proc Devon Archaeol Soc* **49**, 25-97

Maxwell, L 1995 *Hogget Gill Lead Smelter, Hartsop Hall and Brotherswater.* Unpublished report for the National Trust

Maxwell, R 1997 Rough notes on sites associated with Acorn Bank Property. Unpublished notes held by National Trust

Mayer, P 1990 'Calstock and the Bere Alston silver-lead mines of the first quarter of the Fourteenth century' *Cornish Archaeol* **29**, 79-91

Mayers, L 2004 *Balmaidens*. Penzance: The Hypatia Trust

McAree, D 2007 *Archaeological excavation at Cotes Road, Barrow on Soar.* Unpublished report

McCamley, N J 2004 *Disasters Underground.* Barnsley: Pen and Sword

McCann, W 2002 'Chilmark stone quarries and railways' *Journal and Report of Permanent Way Institution Proc* **120.4**, 396 -7; 399 - 400

McKClough, T H and Cummins, W A 1979 *Stone axe studies*. CBA Research Report **23**

McKClough, T H and Cummins, W A 1988 *The petrology of prehistoric stone implements from the British Isles: Stone Axe Studies Volume 2*. CBA Research Report **67**

McCracken, A 1965 'The Glendining Antimony Mine (Louisa Mine)' *Trans Dumfrieshire and Galloway Natural Hist and Antiq Soc* **3.42**, 140-48

McDonnell, J G 1997 'The slags and residues' in D Cranstone 1997 *Derwentcote Steel Furnace: An Industrial Monument in County Durham.* Lancaster Imprints **6**, 93-99

McDonnell, J G, Dockrill, S, Heron, H, Starley, D and Tirpak, J 1992 'Geophysics and Slag Analysis at Grinton Smeltings' in L Willies and D Cranstone (eds) 1992 *Boles and Smeltmills*. London: HMS

McGrath, A 2007 'The Rock Quarries of Charnwood Forest' *Mercian Geologist* **16**, 241-62

McMurtrie, J 1912. 'On a boring at Puriton, near Bridgwater, in search of coal south of the Mendip Hills' *Somerset Archaeol Natur Hist* **57**, 25-53

McNabb, J 1996 'An Archive Report on Recent Excavations at Harrow Hill' *Sussex Archaeological Collections* **134**

McNeil, R (nd) *Two medieval salt houses excavated in Wood Street, Nantwich – 1980*. Salt Museum Publication, Cheshire Libraries and Museums

McNeill, R and Newman, R 2006 'The Industrial and Modern Period Resource Assessment' *Archaeology North West* **8.18**, 165-94

Meade, R 1882 *The Coal and Iron Industries of the United Kingdom*. London: Crosby Lockwood

Medlicott, I R 1983 'John Curr and the development of the Sheffield Collieries, 1781-1805' *Trans Hunter Archaeol Soc* **12**, 51-60

Meharg, A A, Edwards, K J, Schofield, J E, Raab, A, Feldmann, J, Moran, A, Bryant, C L, Thornton, B, Dawson, J J C 2011 'First comprehensive peat depositional records for tin, lead and copper associated with the antiquity of Europe's largest cassiterite deposits' *J Archaeol Science* **30**, 1-11

Mellor, S H 1990 *An Introduction to Crushing and Screening*. The Institute of Quarrying

Melville, J and Hobbs, J L 1951 *Early Railway History in Furness.* Cumberland and Westmorland Antiq and Archaeol Soc, Tract Series XIII

Mercer, R 1981 *Grimes Graves Excavations 1971-72 Volume 1*. HMSO

Mercer, 1986 'The Neolithic in Cornwall' *Cornish Archaeol* **25**, 35-80

Meredith, R 1981 'Millstone making at Yarncliff in the reign of Edward IV' *Derbyshire Arch J* **101**, 102-6

Messenger, M 2002 'The Florence Tramway' *Industrial Railway Record* **170**, 206-14

Messenger, M 2005 *Industrial Railways of the South West.* Truro: Twelveheads

Messenger, M 2007 *North Devon Clay.* Truro: Twelveheads Press (2nd edition),

Michell, F B 1978 'Ore Dressing in Cornwall 1600-1900' *J Trevithick Soc* **6**, 25-52

Middleton, R H 1985 'Survey of the old copper works, Copper Mine Valley, Coniston' *Trans Cumberland and Westmorland Antiq Archaeol Soc* **85**, 273

Mighall, T and Chambers, F 1993a 'The environmental impact of prehistoric mining at Copa Hill, Cwmystwyth, Wales' *The Holocene* **3**, 260-4

Mighall, T M, Dumayne-Peaty, L and Cranstone, D 2004 'A record of atmospheric pollution and vegetation change as recorded in three peat bogs from the Northern Pennines Pb-Zn orefield' *Environmental Archaeology* **9.1**, 13-38

Mighall, T, Timberlake, S, Grattan, J, and Forsyth, S 2000 'Bronze Age Lead Mining at Copa Hill, Cwmystwyth-fact or fantasy?' *Historical Metallurgy* **34.1**, 1-12

Mighall, T M, Timberlake S, Foster, I D L, Krupp, E and Singh, S 2009 'Ancient copper and lead pollution records from a raised bog complex in Central Wales, UK' *Jour Archaeol Science* **36.7**, 1504-15

Miles, H 1975 'Barrows on the St. Austell granite *Cornish Archaeol* **14**, 5-81

Miller, E and Hatcher, J 1995 *Medieval England;Towns, Commerce and Crafts, 1086-1348.* London: Longman

Miller, I (ed) 2002 *Steeped in History:The Alum Industry of North-East Yorkshire*. Helmsley: NYMNPA

Milles, J 1759 'Remarks on the Bovey Coal: In a Letter to the Right Honourable George Earl of Macclesfield, President of the Royal Society' *Philosophical Transactions* **51**, 534-53

Millett, M 1992 *The Romanization of Britain: An Essay in Archaeological Interpretation.* Cambridge: University Press

Milodowski, A E, Strong, G E, Shepherd, T J, Spiro, B, Kemp, S J, Hyslop, E K, Jones, D G, Leng, M J, Haslam, H W, Bradley, A D, Nicolson, R A and Warrington, G 1999 'Diagenesis of the Permo-Triassic rocks' in J A Plant, D G Jones and H W Haslam 1999 (eds), 125-75

Minchinton, W E 1957 *The British Tinplate Industry: A History.* Oxford: Clarendon Press

Mitchell, B R 1984 *Economic Development of the British Coal Industry*. Cambridge: University Press

Money, J H 1974 'Iron Age and Romano-British iron working site in Minepit Wood, Rotherfield, Sussex' *Historical Metallurgy* **8.1**, 1-19

Moore, D T 1978 'The petrography and archaeology of English honestones' *Jour Archaeological Science* **5**, 61-73

Moore, D T 1983 'Petrological aspects of some sharpening stones and touchstones and milling stones' in Kempe and Harvey (eds), 277-300

Moore, D T and Oddy, W A 1985 'Touchstones: some aspects of their nomenclature, petrography and provenance' *Jour Archaeol Science* **12.1**, 59-80

Moore, J 1992 *Llanymynech hillfort – a palynological and geochemical investigation of ancient mining in the Welsh Borders*. Unpublished MSc dissertation, University of Sheffield

Moore, M J 1977 'Carrock Fell Tungsten Mine, Cumbria' *Royal School of Mines Journal* 7-14

Moore,T 1829 *The History of Devonshire from the earliest period to the present*. London: Jenkins

Moorhouse, S A 1981 'Iron Production' in M L Faul and S A Moorhouse (eds) *West Yorkshire: and Archaeological Survey to A.D. 1500*, **3,** 777-9. Wakefield: West Yorks County Council

Moorhouse, S 1990 'The Quarrying of Stone Roofing Slates and Rubble in West Yorkshire' in D Parsons (ed) 1990a,126-145

Moorhouse, S 2007 'A quest for stone: the quarrying of stone for buildings and artefacts in medieval Yorkshire' *Medieval Yorkshire* **36**, 1-29

Morgan, J E 1996 'Iron Ropes for the Cornish Mines' *Mining History: Bull PDMHS* **13.2**, 10-15

Morgan, P and Wood, S 1978 *Domesday Book: Derbyshire*. Chichester: Phillimore

Morgan, V M 1993 *The limekilns and associated quarries in Walford, Ross on Wye.* Ross on Wye Civic Association

Morgans, H M 1930 'A Dressing Plant for Bideford Black' *Trans Institute of Mining and Metallurgy* **39**, 653-63

Moriarty, D 1989 *Building of the Cotswolds*. London: Victor Gollancz

Morris, G 1923 'Some Neolithic Sites in the Upper Valley of the Essex Cam' *Essex Naturalist* **20**, 63-4

Morris, J 1978 *Domesday Book: Cheshire*. Chichester: Phillimore

Morris, J 1980 *Domesday Book: Somerset.* Chichester: Phillimore

Morris, R K 1996 *The Elms Colliery, Nailsea, Somerset: recording and analysis of the surviving buildings*.City of Hereford Archaeological Unit report

Morris, S 1998 *Discover Dorset – Portland*.Wimborne: Dovecote Press

Morrison, J 1998 *Lead Mining in the Yorkshire Dales*. Skipton: Dalesman

Morrison, J 2005 *The Geology of Salt*. Salt Museum Publication, Cheshire Libraries and Museums

Morrison, J (nd) *The Development of the Vacuum Process for the Evaporation of Brine*. Salt Museum Publication, Cheshire Libraries and Museums

Morrison, T A 1975 *Goldmining in Western Merioneth*. Llandysul: published privately

Mott, R A 1969 'Tramroads of the Eighteenth Ceentury and their Originator: John Curr. *Trans Newcomen Soc* **37**, 19-33

Mottershead, G and Wright, J 2008 *Stormy Point, Alderley Edge, Cheshire, An archaeological evaluation.* UMAU report

Mountain, C G 1860 'Description of Machinery for Crushing Stone for Macadmising Roads' *Proc Institution of Mechanical Engineers* 234-47

Murchison, J H 1876 *British lead mines with maps of the Durham, Northumberland, Shropshire, Cardiganshire and Montgomeryshire lead mining districts*. London

Murless, B J 2000 *Somerset Brick and Tile Manufacturers, a brief history and gazetteer*. SIAS Survey **13**

Murphy, F 2015 'Pontrhydygroes, Frongoch Lead Mine SN 7213 7440' *Archaeology in Wales* **54**, 221-22

Murphy, S 1970 "Hand Built' for the Job - An Example of Early Metallurgical Craftsmanship' *Bull PDMHS* **4.4**, 281–9

Murphy, S 1996 *Grey Gold – Men, Mining and Metallurgy at the Greenside Lead Mine in Cumbria.* Tanworth-in-Arden: Moiety

Murphy, S and Baldwin, H 2001 'Early Lead Smelting Sites in the Swaledale area of Yorkshire' *Historical Metallurgy* **35**, 1-21

Murphy, S and Zant, J (forthcoming) 'A Roman lead-smelter and workshop at Botchergate, Carlisle' *Historical Metallurgy*

Musson, C R and Northover, J P 1989 'Llanymynech hillfort, Powys and Shropshire: observations on construction work 1981' *Montgomeryshire Collections* **77**, 15-26

Myerscough, R 2004 *Hildingley Limestone Project*. RVBMRG report

Myerscough, R 2007 *Hildingley Quarries and Slingsby Castle*. RVBMRG report

Nadin, J 1990 *Coal Mining in Nelson and Colne*.

Nadin, J 1997 *The Coal Mines of East Lancashire*. British Mining Monograph **58**

Nadin, J 1999 *Coal Mines Around Accrington and Blackburn.* British Mining Monograph **64**

Nance, R D and Nance, R D 1996 'A Survey of Engine Houses on the Mines of South Devon' *Mining History* **13.2**, 109-22

Nash, D A 1978 'Miss Nellie Kirkham – an obituary' *Bull PDMHS* **7.4**, 195-8

National Association of Mining History Organisations (NAMHO) 2011 *A bibliography for clay quarries, mines and brickpits*. [PDF document] www.vmine.net/namho-2010/research/clay.pdf [accessed 4 March 2012]

Nayling, N 1998 *The Magor Pill Medieval Wreck*. York: CBA

Naylor, P 1984 'The pumps at Mill Close Mine' *Bull PDMHS* **9.2**, 123-6

Neaverson, P 2000 'Califat Colliery, Swanington Common: Site History and Excavation Report' *Trans Leicestershire Archaeol and Hist Soc* **74**, 79-98

Nef, J U 1966 *The Rise of the British Coal Industry*. London: Routledge

Nevell, M 1996 *The 'Pot Shaft' Hoard, Alderley Edge, Cheshire. Coins in Context: the controlled micro-excavation of a fourth-century Roman coin hoard*. UMAU report

Nevell, M and Fielding, A P (eds) 2003 *Brine in Britannia: recent archaeological work on the Roman Salt Industry*. Archaeology North-West **17**

Newell, E 1988 *The British copper ore market in the nineteenth century, with particular reference to Cornwall and Swansea.* Unpublished thesis, University of Oxford

Newman, P 1993 'Week Ford Tin Mills, Dartmoor' *Proc Devon Archaeol Soc* **51**, 185-97

Newman, P 1994 'Tinners and Tenants on south-west Dartmoor: A case study in landscape history' *Rep Trans Devonshire Ass* **126,** 199-238

Newman, P (ed) 1996a *The Archaeology of Mining and Metallurgy in South-West Britain*. PDMHS Mining History Monograph **13:2**

Newman, P 1996b *Tinworking in the O Brook Valley, Dartmoor, Devonshire*. RCHME AI report

Newman, P 1998a *The Dartmoor Tin Industry: a Field Guide*. Newton Abbot: Chercombe

Newman, P 1998b *Ausewell Wood Ore Processing and Smelting Complex, Ashburton, Devon.* RCHME AI report

Newman, P 1999a *Haytor Down, Ilsington, Devon. An Archaeological Survey.* RCHME AI report

Newman, P 1999b 'Eylesbarrow (Ailsborough) Tin Mine' *Proc Devon Archaeol Soc* **58,** 105-48

Newman, P 2002a *Headland Warren and the Birch Tor and Vitifer Tin Mines*. EHAI Report Series **AI/34/2004**

Newman, P 2002b *Shipley Bridge China Clay Works, South Brent, Devon*. EHAI Report Series **AI/35/2002**

Newman, P 2003a 'Druid Mine, Ashburton' *Rep Trans Devonshire Ass* **135**, 173-218

Newman, P 2003b *Doddington Mines, Holford, Somerset*. EHAI Report Series **AI/17/2003**

Newman, P 2003c 'A Mortarstone on Pinchaford Ball' *DTRG Newsletter* **25**, 6

Newman, P 2004a *Caroline Wheal Prosper: a Tin Mine at Buckfastleigh in Devon*. EHAI Report Series **AI/29/2004**

Newman, P 2004b *Ausewell Wood, Ashburton, Devon, Part ii: Ausewell Mine* (Wheal Hazel). EHAI Report Series **AI/09/2004**

Newman, P 2005 *Brookwood and Wheal Emma Mines, Buckfastleigh, Devon.* EHAI Report Series **AI/01/2005**

Newman, P 2006a *Holne Chase Tin Mine, Holne, Devon: an Archaeological Survey*. EHAI Report Series **AI/50/2006**

Newman, P 2006b 'Tin and the Landscape of Medieval Dartmoor' in S Turner (ed) *Medieval Devon and Cornwall: Shaping an Ancient Countryside*. Macclesfield: Windgather

Newman, P 2006c *The Engine House and Wheel House at Brookwood Mine, Buckfastleigh, Devon*. South West Landscape Investigations report on behalf of DNPA

Newman, P 2010a *Environment, Antecedent and Adventure: Tin and Copper Mining on Dartmoor, Devon.* Unpublished PhD thesis, University of Leicester

Newman, P 2010b *Domestic and Industrial Peat Cutting on North-Western Dartmoor, Devonshire: an archaeological and historical investigation*. South West Landscape Investigations report on behalf of DNPA

Newman, P 2011 *The Field Archaeology of Dartmoor*. Swindon: English Heritage

Newman, P 2014a *Archaeological Excavations at Ventiford Basin on the Stover Canal, Teigngrace, Devon, May 2014: First Interim Report*. South West Landscape Investigations report

Newman, P 2014b 'In search of the Dartmoor *carbonarii*' *Dartmoor Magazine* **117**, 21-3

Nicholls, Rev H G 1866 *Iron Making in the Forest of Dean*. (Facsimile edition 1981)

Nickless, E F P, Booth, S J and Mosley, P N 1976 *The celestite resources of the area north-east of Bristol, with notes on occurrences north and south of the Mendip Hills and in the Vale of Glamorgan*. Institute of Geological Sciences, Mineral Assessment Report **25**. London: HMSO

Noall, C 1972 *Botallack*. Truro: Bradford Barton

Noall, C 1983 *Geevor*. Penzance: Geevor Tin Mines PLC

Norgate, M and Norgate, J 2012 *Old Cumbria Gazetteer, Cobalt Mine*. [Web document] www.geog.port.ac.uk/webmap/thelakes/html/lgaz/lk02501.htm [accessed 16 December 2012]

North, F J 1930 *Limestones - Their Origins, Distribution, and Uses*. Thomas Murby

North Pennines Archaeology Ltd (forthcoming) *Nenthead Mines, Nenthead, Alston, Cumbria*. Report for English Heritage

Notholt, A J G and Highley, D E 1973 *Salt*. Mineral Resources Consultative Committee, Mineral Dossier **7**. London: HMSO

Nowakowski, J A 1991 'Trethellan Farm, Newquay: the excavation of lowland Bronze Age settlement and Iron Age cemetery' *Cornish Archaeol* **30**, 5-242

Nowakowski, JA and Quinnell, H 2011 *Trevelgue Head, Cornwall: the importance of C K Croft Andrew's 1939 excavations for prehistoric and Roman Cornwall.* English Heritage and Cornwall County Council

Oakley, M, Radford, S and Knight, D, 2012 *Alston Moor, North Pennines, Miner-Farmer Landscapes of the North Pennines AONB NMP Aerial Investigation and Mapping Report.* Research Report Series **4**. Portsmouth: English Heritage

Oates, J A H 2008 *Lime and limestone: chemistry and technology, production and uses*. New York: John Wiley

O'Brien, W 1994 *Mount Gabriel – Bronze Age Mining in Ireland.* Galway: University Press

O'Brien, W 2005 *Ross Island – Mining, Metal and Society in Early Ireland.* Bronze Age Studies **6**. Galway: National University of Ireland

Oglethorpe, M K 2006 *Scottish Collieries an inventory of the Scottish coal industry in the nationalised era*. Edinburgh: RCAHMS

Orr, K 2006 *An archaeological excavation of a foundation trench at the drama block, St Helena School, Sheepen Road, Colchester, Essex.* CAT Report **384**

Oswald, A 1994 *Harrow Hill, West Sussex*. RCHME survey report

Oswald, A, Hunt, A, Thomas, R J and Stone, J 2005 *Analytical field survey of prehistoric and post-medieval remains on Fylingdales Moor, North Yorkshire*. EHAI Report Series **AI/12/2005**

Oswald, A, McOmish, D and Ainsworth, S 2001 *Greenburn Copper Mine, Cumbria*. EHAI Report Series **AI/6/2001**

Oswald, A and Pearson, T 1999 *Force Crag Mine, Cumbria*. EHAI Report Series **AI/1/1999**

Oswald, A, Newman, P, Went, D and Grindey, C 2008 *Force Crag Mine, Above Derwent, Cumbria: Archaeological Survey of the High Force Workings*. EH Research Report **21/2008**

Ove Arup and Partners Ltd 1993 *Clive Copper Mine Feasibility Study.* Unpublished report for Shropshire County Council

Owen, C 1984 *The Leicestershire and South Derbyshire Coalfield 1200-1900*. Ashbourne: Moorland

Owen, D, Price, W and Reid, C R 2008 *Gloucestershire Cotswolds Geodiversity Audit and Local Geodiversity Action Plan*. Gloucestershire Geoconservation Trust, Gloucester

Owen, J 1998 *Cleveland Ironstone*. Cleveland Industrial Archaeology Society and NYMNPA

Page, W (ed) 1912 *Victoria History of the Counties of England: Yorkshire, North Riding Volume 3*. London: Constable and Co

Page Arnot, R 1949, 1953, 1961, 1979 *The Miners: 1889-1946 (*4 vols). London

Page-Smith, K 2010 *Land at Dark Lane, Broseley, Shropshire. Archaeological Desk-Based Assessment*. Nexus Archaeology Report **3049.R01**

Page-Smith, K 2011a *Land at Dark Lane, Broseley, Shropshire. Archaeological Earthwork Survey*. Nexus Archaeology Report **3070.R01**

Page-Smith, K 2011b *Land at Dark Lane, Broseley, Shropshire. Archaeological Trial Trench Evaluation.* Nexus Archaeology Report **3082.R01**

Palmer, M and Neaverson, P 1987a 'The Ticknall lime industry and its transport system' *LIHS Bull* **10**

Palmer, M and Neaverson, P 1987b *The Bassett Mines: their History and Archaeology.* British Mining Monograph **32**

Palmer, M and Neaverson, P 1989a 'The Comparative Archaeology of Tin and Lead Dressing in Britain during the Nineteenth Century' *Bull PDMHS* **10.6**, 316-43

Palmer, M and Neaverson, P 1989b 'Nineteenth Century Tin and Lead Dressing: a Comparative Study of the Field Evidence' *Industrial Archaeology Review* ***12***, 20-39

Palmer, R 2002 'Homes for Peat Diggers?' in T Lane and J Coles (*eds)* 2002

Palmer-Brown, C 1993 ' Bronze Age Salt' *Current Archaeology* **136**

Pamment, J and Slater, B 1988 'An eighteenth century lead and silver mine near Newton St Cyres' *Proc Devon Archaeol Soc* **46**, 149-53

Papworth, M 1992 *Brownsea Island, Dorse:t National Trust Archaeological Survey.* Unpublished report

Parfitt, S 2006 'First Britons: Pakefield – a weekend to remember' *British Archaeology* **86**

Parker, H M and Willies, L M 1979 *Peakland Lead Mines and Miners*. Ashbourne: Moorland

Parsons, D (ed) 1990a *Stone, Quarrying and Building in England AD 43-1525*. Phillimore and RAI

Parsons, D 1990b *'Review and Prospect: The Stone Industry in Roman, Anglo-Saxon and Medieval England'* in D Parsons (ed) 1990a, 1-15

Parsons, D 1991 'Stone' in J Blair and N Ramsey (eds) 1991, 1-28

Pascoe, W H 1981 *C.C.C. The History of the Cornish Copper Company*. Redruth: Dylanslow

Pashley, V and Evans, J (nd) *The Lead Isotope Composition of Artefacts from the Peak District and Cu alloy from Greece.* NIGL Report **R239**

Paulson, R 1997 *The Derbyshire paint and colour industries from the late eighteenth to early twentieth century.* Unpublished MA dissertation, University of of Nottingham

Paxton, R A 1953 'Alderley Edge mines' *Cave Science* **3**, 71-82

Paynter, S, Claughton, P and Dunkerley, T 2010 'Further work on residues from lead/silver smelting at Combe Martin, north Devon' *Historical Metallurgy* **44.2**, 104-11

Peacock, D P S 1969 'Neolithic pottery production in Cornwall' *Antiquity* **43**, 145-9

Peacock, D P S 1980 'The Roman Millstone Trade: a petrological sketch' *World Archaeology* **12**, 43-53

Peacock, D P S 1987 'Iron Age and Roman quern production at Lodsworth, Sussex' *Antiquaries J* **67**, 61-85

Peacock, D P S 1998 *The Archaeology of Stone*. London: English Heritage

Peacock, D P S and Williams, D F 1999 *Ornamental coloured marble in Roman Britain: an interim report.* Archaeomateriaux: Mabres et autres roches, ASMOSIA IV Bordeaux, 353-7

Pearce, A, Ludditt, R, Straw, M, Taylor, W, Watson, J and Watson, R 1984 'Mouldridge Mine, Pikehall, Derbyshire' *Bull PDMHS* **9.2**, 108-22

Pearce, A 1994 *Metalliferous Mines of Shropshire Volume I – Gazetteer.* Account **20** SCMC

Pearce, A (ed) 1995 *Mining in Shropshire*. Shrewsbury: Shropshire Books

Pearce, A 1997 *Metal Mines of Shropshire*. SCMC: Account **22**

Pearson, A 2006 *The Work of Giants: stone and quarrying in Roman Britain*. Stroud: Tempus

Pearson, T 2000 *Quern Manufacturing at Wharncliffe Rocks, Sheffield, South Yorkshire*. EHAI Research Report **AI/20/2000**

Pearson, T and Hunt, A 2004 *Ayton Banks Alum Works, North Yorkshire*. EHAI Report Series **AI/26/2004**

Peaty, I P 2006 *Moving Mountains By Rail*. Stroud: Tempus

Pengelly, W and Heer, O 1862 ' On The Lignite formation of Bovey Tracey' *Philosophical Transactions* **2**

Penhallurick, R D 1986 *Tin in Antiquity*. London: Institute of Metals

Penhallurick, R D 1997 'The evidence for prehistoric mining in Cornwall', in P Budd and D Gale (eds), *Prehistoric Extractive Metallurgy in Cornwall*. Truro: Cornwall CC

Penn, K 2005 *A desk based survey of land at Setchey, West Winch, Norfolk.* NAU Report **1023**

Pennington, R R 1973 *Stannary Law - A History of the Mining Law of Cornwall and Devon.* Newton Abbot: David and Charles

Penny, R 2009 'An Introduction to the Ecology of Lead Mines in the Peak District' *Mining History* **17.4,** 28-31

Pepper, R 1996 *Eston and Normanby Ironstone Mines*. Cleveland Ironstone Series, Guisborough: Peter Tuffs

Perkins, J W, Brooks, A T and Pearce, A E 1979 *Bath Stone, A Quarry History*. Bath: Kingsmead for Univ College Cardiff

Perry, R and Thurlow, C 2010 *Extraordinary Earths*. St Austell: Cornish Hillside

Petch, J A 1925 'Roman Durham' *Archaeologia Aeliana* **4.1**, 1-35

Peters, C 2007 *Archaeological Landscape Survey of land at Hedleyhope Fell, Tow Law, County Durham*. NPAL report

Petts, D with Gerrard, C 2006 *Shared Visions: The North-East Regional Research Framework for the Historic Environment*. Durham County Council, chapter 18, 278

Pettus, J 1670 *Fodinae Regales*. London: Thomas Basset

Pickin, J 1974 'Dog Mine – Alderley Edge' *Sheffield University Speleological Soc J* **2.3**, 29-30

Pickin, J 1990 'Stone Tools and Early Metal Mining in England and Wales', in P Crew and S Crew (eds) 1990, 39–42

Pickin, J 1991 'Site No. 8 Alderley Edge' in C R Blick (ed) *Early Metallurgical Sites in Great Britain*, 66-71. London: The Institute of Metals

Pickin, J 1999 'Stone hammers from the Ecton Mines in the Bateman Collection, Sheffield' *Mining History: Bull PDMHS* **14.2**, 15-18

Pickin, J 2004 'Streaming and hushing for Scottish Gold: The archaeology of early gold working at Leadhills and Wanlockhead' *Mining History: Bull PDMHS* **15.4/5**, 83-6

Pickin, J 2013 *Talnotry Arsenic Mine*. Unpublished report submitted to the Forestry Commission (Scotland)

Pickin, J and Worthington, T 1989 'Prehistoric mining hammers from Bradda Head, Isle of Man' *Bull PDMHS* **10.5**, 274–5

Pierre, F and Wéber, A 2011 'The use of gunpowder in 1617 in the mines of Le Thillot (Vosges-France) - inspiration or imitation in this innovative process' in P Claughton and C Mills (eds) *Mining Perspectives.* Truro: Cornwall CC, 30-47

Pirt, W K 2002 'Slagged Refractory Brickwork From Derwent Smelting Mill' *British Mining Memoirs* **71**, 59-67

Pirt, W K and Dodds, J M 2002 *Lead Mining in the Derwent Valley*. British Mining Monograph **70**

Plant, J A, Jones, D G and Haslam, H W (eds) 1999 *The Cheshire Basin – Basin evolution, fluid movement and mineral resources in a Permo-Triassic rift setting*. Nottingham: British Geological Survey

Plant, J A, Ball, D F, Bradley, A D, Chadwick, R A, Evans, D J, Jones, D G, Kirby, G A, Milodowski, A E, Nicholson, R A, Shepherd, T J, Smith, N J P, Warrington, G and Wilson, A A 1999 'Resources of the basin: base metals, industrial mineral, hydrocarbons and groundwater' in Plant, J A, Jones, D G and Haslam, H W (eds) *The Cheshire Basin: basin evolution, fluid movement and mineral resources in a Permo-Triassic rift setting*. Keyworth, Nottingham: British Geological Survey, 210-239

Plant, K P 1968 'Industrial Railways of Lincolnshire (4) North Killingholme Clayfields' *Industrial Railway Record* **22**, 359-64 [Web document] www.irsociety.co.uk/archives/22/lincs_4.htm [accessed 3 March 2012]

Plint, R G 1962 'Stone axe factory sites in the Cumbrian Fells' *Trans Cumberland and Westmorland Antiq and Archaeol Soc* **62**, 1-26

Plint, R G 1978 'More Stone Axe Factory Sites in the Cumbrian Fells' *Trans Cumberland and Westmorland Antiq and Archaeol Soc* **78**, 81-15

Pliny the Elder 1992 *Natural History*. London: Harvard University Press. (10 vols). Latin text with English translation

Pollard, S and Crossley, D W 1968 *The Wealth of Britain, 1085-1966*. London: Batsford

Polwhele, R 1797 *History of Devonshire, Volume 2*. London

Ponsford, M 1993 'Post-medieval Britain and Ireland in 1992' *Post-medieval Archaeol* **27**, 205-96

Poole, E G and Williams, B J 1980 *The Keuper Saliferous beds of the Droitwich area*. Report of the Institute of Geological Sciences **81/2**. London: HMSO

Popplewell, L 1988 *Stone Blocks and Greenheart - Swanage Seen From Its Piers*. Bournemouth: Melledgen Press

Porter, L 2004 *Ecton Copper Mines under the Dukes of Devonshire: 1760-1790*. Ashbourne: Landmark.

Porter, L and Robey, J 1972a 'The Royledge and New York copper mines, Upper Elkstones, near Leek, Staffordshire' *Bull PDMHS* **5.1**, 1-9

Porter, L and Robey, J 1972b 'The metalliferous mines of the Weaver Hills, Staffordshire. Part II – the Ribden mines' *Bull PDMHS* **5.1**, 14-30

Porter, L and Robey, J 2000 *The copper and lead mines around the Manifold Valley: North Staffordshire*. Ashbourne: Landmark

Postles, D1979 'Early Coalmining at West Hallam' *Derbyshire Arch J* **159**, 221

Postlethwaite, J 1877 (1987) *Mines and Mining in the English Lake District*. Whitehaven: Michael Moon (3rd revised edition 1987)

Powell, A J 2005 *Geophysical survey of lead smelting features identified on Totley bole hill, Blacka Moor nature reserve, Sheffield.* Report by Dept of Archaeological Science, University of Bradford [Web document] http://ads.ahds.ac.uk/catalogue/adsdata/arch-948-1/dissemination/pdf/appendices/40._totley_bole_hill_geophysical_survey_report.pdf

Powell, A J 2008 *The Magnetic Signatures of Medieval and Post-medieval Pyrotechnical Industries*. Unpublished PhD, thesis, University of Bradford

Powell, S 1999 'The Dudley Limestone Mines' *Mining History : Bull PDMHS* **14.1**, 1-68

Poyner, D and Evans, R 2000 *The Wyre Forest Coalfield.* Stroud: Tempus

Prag, A J N W (ed) 2016 *Living with the Edge: Alderley's Story*. Manchester: University Press

Preece, G and Ellis, P 1981 *Coalmining*. City of Salford Cultural Services

Price, A 2007 *Cheltenham Stone: The Whittington Quarries*. Cotswold Naturalists Field Club report

Price, D, Wright, W B, Jones, R C B, Tonks, L H and Whitehead, T H 1963 *Geology of the country around Preston. Memoir of the Geological Survey of Great Britain, Sheet 75 (England and Wales)*. London:HMSO

Price, L 1984 *Bath Freestone Workings*. Bath: Resurgence Press

Prince, H C 1964 'The origin of pits and depressions in Norfolk' *Geography* **49**,15-32

Pryce, W 1778 *Mineralogia Cornubiensis*. London: Philips

Pugh, P 1988 *The History of Blue Circle*. Cambridge Business Publishing

Pugh, W 1960 'Triassic salt: discoveries in the Cheshire-Shropshire Basin' *Nature* **187** (No 4734), 278-9

Purcell, D 1967 *Cambridge Stone*. London: Faber

Pushman, D 1995 *Swanworth: History of Swanworth Quarry, Dorset, part of Tarmac plc*. Published privately

Pybus, D and Rushton, J 1991 'Alum and the Yorkshire coast' in D B Lewis (ed) *The Yorkshire Coast*. 46-59. Beverley: Normandy Press

Pye, A R 1991 *Archaeological Assessment of the Stover and Hackney Canals and Hackney Quay*. EMAFU Report **91.16**

Pye, A and Dixon, T 1989 'The Arsenic Works at Devon Great Consols Mine, Tavistock' *Proc Devon Archaeol Soc* **47**, 79-112

Pye, A and Weddell, P 1992 'A Survey of the Gawton Mine and Arsenic Works, Tavistock Hamlets, West Devon' *Industrial Archaeology Review* **15**, 62-96

Pye, A and Westcott, K A 1992 *An Archaeological Survey of the Pumping Engine House at Wheal Betsy, Mary Tavy*. EMAFU Report **92.08**

Quinnell, H 1986 'Cornwall during the Roman period' *Cornish Archaeol* **25**, 111-34

Quinnell, H 1987 'Cornish gabbroic pottery: the development of a hypothesis' *Cornish Archaeol* **26**, 7-12

Quinnell, H 2004 *Trethurgy: Excavations at Trethurgy Round, St. Austell: Community and Status in Roman and Post-Roman Cornwall*. Truro: Cornwall County Council

Radford, S and Pallant, G 2008 *Durham- Assessment of Archaeological Resource in Aggregate Areas*. Revised Interim Report for English Heritage National Mapping Programme

Railton, M and Wooler, F 2012 *Miner Farmer Landscapes of the North Pennines AONB Block 2A: Landscape Survey*. WAA Report **CP1262/12**

Raine, J (ed) 1837 The Priory of Finchale: The Charters of Endowments, Investments and Account Rolls, of the Priory of Finchale in the County of Durham. Surtees Society **6**, ccclxxv. Expensae ….*Et in falcacione et lucracione foeni apud Morehousclose et Fynkhall, xxiiiijs. Et in nova construccione unius domus porcorum continentis sex domunculas xjl. viiijs. Et in expensis factis circa novam ordinacionem de le pompe, cum construccione unius domus, et factura omnium necessariorum ejusdem, cum equis emptis ac necessariis eorumdem, ixl. xvs. Vjd*

Rainsford Hannay, F 1999 *Dry stone walling*. Carnforth: Dry Stone Walling Association(reprint)

Raistrick, A 1936 'The Copper deposits of Middleton Tyas, North Yorks' *The Naturalist*, 111-15

Raistrick, A 1939 'The South Yorkshire iron industry 1698-1756' *Trans Newcomen Soc* **19**, 51-86

Raistrick, A 1973 *Lead Mining in the mid-Pennines: the mines of Nidderdale, Wharfedale, Airedale, Ribblesdale and Bowland*. Truro: Bradford Barton

Raistrick, A 1975 *The Lead Industry of Wensleydale and Swaledale.* (2 vols). Buxton: Moorland.

Raistrick, A and Jennings, B 1965 *A History of Lead Mining in the Pennines*. Longmans, Green and Co.

Raistrick, A and Roberts, A 1990 *Life and Work of the Northern Lead Miner.* Stroud: Alan Sutton

Ramsden, J V 1937 *The mineral deposits and mines of the Teign Valley, Devonshire.* Unpublished typescript, Devon Heritage Centre, Exeter

Ramsey, D 2007 *The Leicestershire Slate Industry from Roman Times to closure in 1908*. LIHS Bulletin **8**

Rattenbury, G and Lewis, M J T 2004 *Merthyr Tydfil Tramroads and their Locomotives*. Oxford: Railway and Canal Historical Society

Raybould, T J 1973 *The Economic Emergence of the Black Country: A Study of the Dudley Estate*. Newton Abbot: David and Charles

RCHME 1993 *Colliery Buildings, Comberwood Farm, Barlborough*. Historic Building Report

RCHME 1994a *Seaham Colliery, Seaham, County Durham*. Historic Building Report

RCHME 1994b *Easington Colliery, County Durham.* Historic Building Report

RCHME 1994c *Prince of Wales Colliery, Pontefract, West York*. Historic Building Report

RCHME 1994d *Bolsover Colliery, Old Bolsover, Derbyshire*. Historic Building Report

RCHME 1994e *Creswell Colliery, Elmton and Creswell, Derbyshire*. Historic Building Report

RCHME 1994f *Markham Colliery, Staveley, Derbyshire*. Historic Building Report

RCAHMS 1997 *Eastern Dumfrieshire: an archaeological landscape.* Edinburgh: HMSO

Read, H H 1962 *Rutley's Elements of Mineralogy*. London: George, Alan and Unwin

Redwood, Sir B, Dalton, W H (ed), and Dalton, L V 1906 *Petroleum*. London: C Griffin and Co (2nd edn)

Revell, D and Baldwin, A 1985 *The Changing Faces of Rossendale*. Rossendale Groundwork

Reynolds, A 2000 *United Mines, St Day, Cornwall - Structural Consolidations Mitigation Recording*. Cornwall CC HES Report **2000R023**

Rhodes, J H 1970 *The London Lead Company in North Wales 1693-1792.* Unpublished PhD thesis, University of Leicester

Richards, C 1971 'Singing River Mine: A Calamine Working at Shipham' *J Bristol Industrial Archaeol Soc* **4**, 7-9

Richards, C 1975 *The Singing River Mine*. Unpublished report and plans held in Somerset HER

Richardson, G H 1962 'Recent Roman Discoveries At Piercebridge' *DNAAS Trans* **11.3-4**

Richardson, P H G 1992 *Mines of Dartmoor and the Tamar Valley After 1913*. British Mining Monograph **44**

Riddler, G P 1981 'The distribution of the Röt Halite Member in North Yorkshire, Cleveland and North Humberside' *Proc Yorkshire Geological Soc* **43.3**, 341-346

Ride, D J 1989 'An account of an excavation of a prehistoric flint mine at Martins Clump, Over Wallop, Hampshire, 1954-5' *Proc HFCAS* **45**, 213-5

Riden, P 1993 *A Gazetteer of Charcoal-fired Blast Furnaces in use since 1660*. Cardiff: Merton Press (2nd edition)

Ridgway, M H 1958 'Medieval Industries and Trade' in D Sylvester and G Nulty (eds) *The Historical Atlas of Cheshire*. Chester: Cheshire Community Council, 26-7

Rieuwerts, J H 1991 'An early Barmote Court dispute and some facts relating to Flots, Floats, Flats and Pipes' *Bull PDMHS* **11.3**, 145-47

Rieuwerts, J H 2007 *Lead Mining in Derbyshire: History, Development and Drainage. 1. Castleton to the River Wye*. Ashbourne: Landmark

Rieuwerts, J H 2008 *Lead Mining in Derbyshire: History, Development and Drainage. 2. Millers Dale to Alport and Dovedale*. Ashbourne: Landmark

Rieuwerts, J H 2010 *Lead Mining in Derbyshire: History, Development and Drainage. 3. Elton to the Via Gellia*. Ashbourne: Horizon Press

Rieuwerts, J H 2012 *Lead Mining in Derbyshire: History, Development and Drainage. 4. Cromford, Wirksworth, including Ashover and Crich*. Matlock Bath: PDMHS

Riley, H 2000 *Colton Pits, Nettlecombe, Somerset: early iron ore extraction pits and 19th/20th century mining*. EHAI Research Report **AI/5/2000**

Riley, H and Wilson-North, R 2001 *The Field Archaeology of Exmoor*. Swindon: English Heritage

Rippon, S, Claughton, P and Smart, C 2009 *Mining in a Medieval Landscape – The Royal Silver Mines of the Tamar Valley*. Exeter: University Press

Ritchie, A E 1922 *The Kent Coalfield, Its Evolution and Development. London:* Iron and Steel Trades Review

Ritchie, B 1999 *The Story of Tarmac*. London: James and James

Robb, L J 2005 *Introduction to Ore-Forming Processes*. Blackwell Publishing

Roberts, A F and Leach, J 1985 *The Coal Mines of Buxton.* Cromford: Scarthin

Roberts, I D 2000 'Iron Making in Redesdale and North Tynedale in the Nineteenth Century: The problems of rural exploitation and diversification' *Northern History* **36.2**, 283-97

Roberts, J 1982 'Charterhouse Rakes' *Mendip Caving Group J* **7**, 40-49

Roberts, S 2012 'Dorset's Ball Clay Tramways' *Plymouth Mineral and Mining Club J* **42.2**, 8-10

Robey, J A and Porter, L 1970 'The copper and lead mines of the Mixon area, Staffordshire' *Bull PDMHS* **4.4**, 256-80

Robey, J A and Porter, L 1971 'The metalliferous mines of the Weaver hills, Staffordshire' *Bull PDMHS* **4.6**, 417-427

Robey, J A and Porter, L 1972 *The Copper and Lead Mines of Ecton Hill, Staffordshire*. Ashbourne: Moorland

Robinson, H 1958 'Cheshire's Inland Waterways' in D Sylvester and G Nulty (eds) *The Historical Atlas of Cheshire*. Chester: Cheshire Community Council, 56-57

Rochester, M (nd) *Rock Salt Mining in Cheshire*. Salt Museum Publication, Cheshire Libraries and Museums

Rochester, M (nd) *The Growth of the Salt Industry in the 19th century*. Salt Museum Publication, Cheshire Libraries and Museums

Rochester, M 1985 *Salt and Subsidence*. Salt Museum Publication, Cheshire Libraries and Museums (2005 reprint)

Roe, M 2000a *An Integrated Study of the Underground and Surface Archaeology of Cononley Lead Mine, North Yorkshire.* Unpublished BSc dissertation, University of Leicester

Roe, M 2000b 'The Archaeology of Thieveley Lead Mine, near Burnley' *British Mining Memoirs* **67**, 99-107

Roe, M 2003a 'Greenhow Hill Lead Mines Survey' *British Mining Memoirs* **73**, 89-103.

Roe, M 2003b *Greenhow Hill Lead Mines Survey.* Unpublished report for Nidderdale AONB. NMRS

Roe, M 2003c 'Lead Mining in the Yorkshire Dales' *Landscapes* **4.1**, 65-78

Roe, M 2004 'Sir Francis Level: Driven by Water' *in* P Claughton (ed) 2004, 87-92

Roe, M 2006 'Recording Mining Landscapes in the Yorkshire Dales: The Contribution of the Northern Mine Research Society' *Industrial Archaeology Review* **28.2**, 118-22

Roe, M 2007 'Hidden Boundaries/Hidden Landscapes: Lead Mining Landscapes in the Yorkshire Dales' *in* Barnwell, P S and Palmer, M (eds) *Post-Medieval Landscapes*. Macclesfield: Windgather

Roe, M 2008 *Middleton Park Community Archaeological Survey*. [PDF document] www.fomp.co.uk/downloads/survey/finalreportpart1.pdf

Roe, M and Davies, A 2002 'A survey of the area around Jamie Mine, Sun Side Allotment, Appletreewick, North Yorkshire' *British Mining Memoirs* **71**, 68-78

Roe, M, Vernon, R and Gill, M C 1999 'Grassington Low Smelt Mill' *British Mining Memoirs* **63**, 118-30

Roeder, C 1901 'Prehistoric and subsequent mining at Alderley Edge, with a sketch of the archaeological features in the neighbourhood' *Trans Lancashire and Cheshire Antiquarian Soc* **19**, 77-118

Roeder, C and Graves, F S 1905 'Recent archaeological discoveries at Alderley Edge' *Trans Lancashire and Cheshire Antiquarian Soc* **23**, 17-29

Rohl, B and Needham, S 1998 *The circulation of metal in the British Bronze Age: the application of lead isotope analysis*. London: British Museum Occasional Paper **102**

Rowles, A 1992 *Winding Up - A History of Birley East Colliery*. Published privately

Rowley, N 2012 *The Boulby Potash Mine*. Oral presentation to the National Association of Mining History Organisations' annual conference at Quarry Bank Mill, Styal

Ruffell, A H, Holliday, D W and Smith, D B 2006 'Permian: arid basins and hypersaline seas' in P J Brenchley and P F Rawson (eds), *The Geology of England and Wales*. London: The Geological Society, 269-93 (2nd edition)

Russell, A 1949 'The Wherry mine, Penzance, its history and its mineral productions' *Mineralogical Magazine* **28** (No 205), 517-33

Russell, M 2001a *Flint Mines in Neolithic Britain*. Gloucester: Tempus

Russell, M (ed) 2001b *Rough Quarries Rocks and Hills: John Pull and the Neolithic Flint Mines of Sussex*. Oxford: Oxbow

Russell, P M G 1968-70 'Manganese Mining in Devon' *DCNQ* **31**, 205-13

Scott-Garrett, C 1959 'Roman Iron Mine in Lydney Park' *Trans Bristol and Gloucestershire Archaeol Soc* **78**, 86-91

Scrivener, R C and Bennett, M J 1983 'Ore genesis and controls of mineralisation in the Upper Palaeozoic rocks of north Devon' *Proc Ussher Soc* **5**, 54-8

Scrivener, R C, Darbyshire, D P F and Shepherd, T J 1994 'Timing and significance of crosscourse mineralization in SW England' *J Geological Society, London* **151.4**, 587-90

Scrivener, R C, Highley, D E, Cameron, D G, Linley, K A and White, R 1997 *Mineral Resource Information for Development Plans, Phase One, Cornwall: Resources and Constraints*. Keyworth: British Geological Survey [PDF document] www.bgs.ac.uk/downloads/start.cfm?id=2607 [accessed 13 January 2013]

Scrivener, R C and Shepherd ,T J 1998 'Mineralization' in Selwood, et al. (eds) *The Geology of Cornwall*. Exeter: University Press, 136-57

Sealey, P R 1995 'New light on the salt industry and Red Hills of Prehistoric and Roman Essex' *Essex Archaeol and Hist* **26**, 65-85

Searle, A B 1923 *Sands and Crushed Rocks, Volume 2*. Oxford Technical Publications

Searle, A B 1935 *Limestone and its Products*. London: Benn

Selwood, E B, Durrance, E M and Bristow, C M 1998 *The Geology of Cornwall*. Exeter: University Press

Semmens, P W B 1970 'The chemical industry of Teesside and south Durham' in J C Dewdney (ed) *Durham County and City with Teesside*. Durham: The British Association, 330-40

Senior, J B 1990 'Hildenley limestone: a fine quality dimensional and artefact stone from Yorkshire' in D Parsons (ed) 1990a, 147-168

Senior, J R 1999 'The Stonework and Quarries Appendix A' in Fergusson, P and Harrison, S (eds) *Rievaulx Abbey*. Paul Mellon Foundation/Yale, 215-19

SGMRG 2008 *Kingswood Coal: history and location of coal mining sites in Bristol and South Gloucestershire*. Thornbury: SGMRG

SGMRG 2009 *Frog Lane Colliery sixty years on*. Thornbury: SGMRG

Shadmon, A 1996 *Stone – An Introduction*. Intermediate Technology Publications Ltd (2nd edition)

Shaffrey, R 2006 *Grinding and Milling – A study of Romano-British rotary querns and millstones made from Old Red Sandstone*. BAR British Series **409**. Oxford: Archaeopress

Shambrook, H R 1982 *The Caradon and Pheonix Mining Area*. British Mining Monograph **20**

Sharpe, A 1986a Engine *Houses in St Agnes Cornwall - An Archaeological Survey, Volume 1*. Cornwall CC Report **1986R013**

Sharpe, A 1986b *Engine Houses in St Agnes Cornwall - An Archaeological Survey, Volume 2*. Cornwall CC Report **1986R014**

Sharpe, A 1986c *Engine Houses in St Agnes Cornwall - An Archaeological Survey, Volume 3*. Cornwall CC Report **1986R015**

Sharpe, A 1989 *Tresavean Mine, Lanner - An Archaeological Report*. Cornwall CC HES Report **1989R015**

Sharpe, A 1990 *Coastal Slate Quarries, Tintagel to Trebarwith*. Truro: Cornwall CC report

Sharpe, A 1992 *St Just - An Archaeological Survey of the Mining District*. (2 vols). Truro: Cornwall CC report

Sharpe, A 1993a *Wheal Plenty, North Briggan - An Archaeological Assessment*. Cornwall CC HES Report **1993R031**

Sharpe, A 1993b *Kerrier Land Recalamation Scheme, Dolcoath Stamps, - An Archaeological Assessment*. Cornwall HES Report **1993R032**

Sharpe, A 1993c *Minions: An Archaeological Survey of the Caradon Mining District*. Truro: Cornwall CC Report (revised edition)

Sharpe, A 1994 *Levant Calciners: An Archaeological Survey of Levant Calciners and associated flues, condensing labyrinths and chimney stack prior to and during DLG works to reduce the public hazard of arsenical contamination on the site*. Cornwall CC Report **1994R049**

Sharpe, A 1996 *Rosevale Mine – The Excavation of a "lode back" pit on Trewey Common*. Cornwall CC Report **1996R057**

Sharpe, A 1997 '*Smoke but no fire, or the mysterious case of the missing miner'* in Budd and Gale (eds) 1997

Sharpe, A 2006 *Mineral Tramways Project, Unity Wood, Chacewater, Cornwall – Findings of consultancy and archaeological watching briefs during building consolidation and shaft safety works*. Cornwall CC Report **2006R082**

Sharpe, A 2007a *West Basset Trail, Carnkie, Cornwall – Archaeological Assessment*. Cornwall HES Report **2007R033**

Sharpe, A 2007b *The Mineral Tramways Project, Thomas' Shaft, West Basset, Piece, Cornwall.* Cornwall CC Report **2007R070**

Sharpe, A 2009 *Structures at Taylor's and Davey's Shafts, Consolidated Mines, Gwennap - Archaeological Assessment*. Cornwall HES Report **2009R019**

Sharpe, A Lewis, R, Massie, C and Johnson, N 1991 *Engine House Survey The Mineral Tramways Project.* Cornwall CC Report **1991R008**

Shaw, M 2003 'Mining on Cothercott Hill' *SCMC Annual Journal* **8,** 32-49

Shaw, M 2007 *The Shropshire Barytes Industry.* Unpublished MPhil thesis, University Birmingham

Shaw, M 2009 *Lead, Copper and Barytes Mines of Shropshire*. Herefordshire: Logaston Press

Shaw, M (forthcoming) *The Shrewsbury Coalfields*.

Shaw, M, Poyner, D and Evans, R 2015 *Aerial Ropeways of Shropshire*. SCMC Account **15**

Shaw, R P 1995 'Long Rake Spar Mine' *Mining History: Bull PDMHS* **12.5,** 35-37

Shaw, R P 2002, 'Arbor Low Calcite Mine' *Mining History: Bull PDMHS* **15.1,** 38-42

Shaw, W T 1975 *Mining in the Lake Counties*. Clapham: Dalesman

Shelley, J 1998 'A brief guide to flotation technology' *Mining History* **13.6**, 29-32

Shercliff, W H, Kitching, D A and Ryan, J M 1983 *Poynton A Coalmining Village; social history, transport and industry 1700–1939*. W H Shercliff [There is also a website www.brocross.com/poynton/intro.htm]

Sherlock, R L 1921 *Rock-Salt and Brine*. Memoirs of the Geological Survey, special reports on the Mineral Resources of Great Britain **18.** London: HMSO

Sherlock, R L 1938 'Part II - Celestine and Strontianite' in Sherlock, R L and Hollingworth, S E *Gypsum and Anhydrite, Celestine and Strontianite*. Memoirs of the Geological Survey, special reports on the Mineral Resources of Great Britain **3**. London: HMSO (3rd edition) 77-82

Sherlock, R L and Hollingworth, S E 1938 'Part I - Gypsum and Anhydrite' In Sherlock, R L and Hollingworth, S E *Gypsum and Anhydrite, Celestine and Strontianite*. Memoirs of the Geological Survey, special reports on the Mineral Resources of Great Britain **3**. London: HMSO (3rd edition) 1-76

Short, C C 1997 'An outline of the history and industrial archaeology of the flotation process for mineral separation' in B Chambers (ed) *Out of the Pennines*. Killhope, County Durham: Friends of Killhope, 91-94

Silvertant, J 2009 'The medieval Quarry "22, Berkelstreet" beneath Valkenberg Castle (NL) revisited and documented' in J Silvertant (ed) *Recognition, Investigation and Preservation of ancient Mining Relics*. Maastricht/ Reichelsheim: Institute Europa Subterranea, 9-13

Silvertant, J and Mhairin, J N 2009 *What Lies Beneath*. Maastrichte: Institute Europa Subterranea

Simco, A 1998 *Monuments Protection Programme, The Clay Industries, Step 1 Report.* Report for English Heritage

Sinclair, J 1791-99 *Statistical Account of Scotland.* (21 vols) Edinburgh

Singer, C 1948 *The Earliest Chemical Industry: An Essay in the Historical Relations of Economics and Technology Illustrated from the Alum Trade*, London: The Folio Society

Sirius Minerals (nd) *York Potash Project.* [Web document] http://siriusminerals.com/york-potash-project [accessed 15 October 2012]

Sitch, B 2007 'Two 19th century Leeds antiquaries: James Wardell and John Holmes' *Medieval Yorkshire* **36**, 37-49

Skempton, A W 2002 *A Boigraphical Dictionary of Civil Engineers in Gt Britain and Ireland*. London: ICE and T Telford Ltd

Skillen, B S 1989 'Aspects of the Alum Mining Industry about Glasgow' *British Mining Memoirs* **39**, 53-60

Slader, J M 1965 *Days of Renown the story of mining on Exmoor and the Border Parishes. West Country Handbook No.6*. Bracknell: West Country Publications

Smale, C V 1993 'South Terras, Cornwall's Premier Uranium and Radium Mine' *Journal of the Royal Institution of Cornwall* (New Series) **1.3**, 304-21

Small, F and Stoertz, C 2006 *The Forest of Dean Mapping Project, Gloucestershire: A report for the National Mapping Programme*. EH Research Report **28/2006**

Smart, C 2014 *Archaeological Excavation at Churchill's Farm, Hemyock, Devon 2008: Post-Excavation Assessment Report and Updated Project Design.* Unpublished report for English Heritage

Smith, B 1919 'The Chellaston Gypsum Breccia' *Quarterly Journal of the Geological Society of London* **74.3**, 174-203

Smith, D B 1974 'Evaporites' in D H Rayner and J E Hemingway (eds) *The Geology and Mineral Resources of Yorkshire*. Yorkshire Geological Society, 337-44

Smith, D B 1989 'The late Permian palaeogeography of north-east England' *Proc Yorks Geological Soc* **47.4**, 285-312

Smith, D M 1965 *The Industrial Archaeology of the East Midlands*. Newton Abbot: David and Charles

Smith, J R 1988 *Luxulyan Valley Project*. Truro: CAU report

Smith, J R 1992 *Cornwall's China Clay Heritage*. Truro: Twelve Heads Press

Smith, J R 1999 *Wheal Martyn, Carthew – An Archaeological Assessment*. CAU Report **1999R072**

Smith, J R 2008 *Sky-Tips in the St Austell China Clay District - an Archaeological Assessment*. Cornwall CC HES Report **2008R041**

Smith, J R and Buck, C 1994 *Garkar China Clay and Tinworks, Tregrehan, St Austell - Archaeological Assessment.* CAU report **1994R053**

Smith, J R and RCHME 1996 *Shaugh Bridge China-Clay Works: An Archaeological Evaluation*. CAU report

Smith, R 2006a 'A typology of lead-bale slags based on their physico-chemical properties' *Historical Metallurgy* **40.2**, 115-28

Smith, R 2006b 'Radiocarbon Dating of Early Lead Smelting Sites' *British Mining Memoirs* **80**, 94-110

Smith, R 2008 'Lead smelting mill at Scargill, County Durham' *British Mining Memoirs* **86,** 47-58

Smith, R 2011 'Bale Smelting in the Dales' *British Mining Memoirs* **92**, 90-107

Smith, R S 1957 'Huntingdon Beaumont: Adventurer in Coal Mines' *Renaissance and Modern Studies* **1**, 115-53

Smith, R S 1966 'Economic Development: Early Coal and Iron Industry' *Nottingham and its Region.* British Association for the Advancement of Science, 235-41

Smith, R, Laurie, T, MIlls, A and Vernon, R 2014 'Excavation of an early lead smelting site at Hagg Farm, Fremington, Swaledale' *British Mining Memoirs* **98**, 2-33

Smith, R and Murphy, S 2003 'Bale Smelting Sites at Calver Hill, Swaledale, Yorkshire' *British Mining Memoirs* **73**, 46-71

Smith, R and Murphy, S 2010 'Lead bale sites in Nidderdale' *Historical Metallurgy* **44.2**, 81-103

Smith, R and Murphy, S 2011 *Mines of the West Pennines.* British Mining Monograph **91**

Smith, T A and Brown, R 2006 'Excavations and Geophysical Survey of the Roman Settlement at Charterhouse-on-Mendip, 2005' *Somerset Archaeol Natur Hist* **149**, 79-88

Sommers, M 2008 *Historic Building Record 'Brickfields' Saxmundham Road Aldeburgh*. Suffolk CC Archaeological Service, Field Projects Team [PDF document] http://archaeologydataservice.ac.uk/catalogue/adsdata/arch-415-1/dissemination/pdf/suffolkc1-52644_1.pdf [accessed 5 March 2012]

Soper, D 19189 'The Experimental Production of a Replica Shale Cup from Farway Devon' *Proc Devon Archaeol Soc* **47**, 113-6

Sopwith, T 1833 *An Account of the Mining District of Alston Moor, Weardale and Teesdale*. Newcastle-upon-Tyne: Davis Books (1984 reprint)

Sowan, P W 1974 'Firestone mining at Godstone' *Croydon Caving Club: Pelobates* **25**, 8-9, 12

Sowan, P W 1976 'Chalk mining in east Surrey' *Surrey History* **1.3**, 83-94

Sowan, P W 1984 'Further light on the Gatton and Guildford stone quarries in the sixteenth century' *Proc Geologists' Ass* **86.8**, 193-4

Sowan, P W 1987 *Underground archaeology as observed in the Merstham, Chaldon and Godstone quarries, east Surrey*. Croydon Natural History and Scientific Soc, Industrial Studies Section **8**

Sowan, P W 1991 *Underground archaeology : some archaeological opportunities characteristic of underground mines and quarries*. KARG Research Report **10**, 35-40

Sowan, P W 2000 'The Reigate Stone Research Project' *Bull Surrey Archaeol Soc* **335**, 1-5

Spalding, A, Hartgroves, S, Macadam, J and Owens, D 1999 *Abandoned Pits and Quarries in Cornwall*. Truro: Cornwall CC

Spence, R T 1991 'Mining and Smelting by the Cliffords, earls of Cumberland, in Westmorland in the early Seventeenth Century' *Trans Cumberland and Westmorland Antiq and Archaeol Soc* **XCI**, 101-17

Spensley, I M 2010 'The historical development of lead mining in the Wensleydale area to 1830' *British Mining Memoirs* **90**, 172-93

Spensley, I 2014 *Mines and Miners of Wensleydale: an extensive history of Wensleydale's mining industry*. Published privately

Spratt, D A and Inman, R 1986 *Site 38 (Hayes) Roxby Moor.* Teeside Archaeological Society unpublished report

SPRS 1985 *Priorities for the preservation and excavation of Romano-British sites*. London: Society for the Promotion of Roman Studies

Squire, M (nd) *Social and Environmental Conditions in the Salt Industry*. Salt Museum Publication, Cheshire Libraries and Museums

Squires, S and Russell, R 1999 'Claxby Ironstone Mine' *Lincolnshire Hist and Archaeol* **34**, 46-58

Squires, S 2003 'Claxby Ironstone Mine' *Lincolnshire Hist and Archaeol* **38**, 34-36

Stafford, P 1985 *The East Midlands in the Early Middle Ages*. Leicester: University Press

Stamper, J M B 1985 'The Shropshire salt industry' *Trans Shropshire Archaeol Soc* **64**, 77-82

Stanes, R G F 1993 'Devonshire Batts: The whetstone mining industry and community of Blackborough, in the Blackdown Hills' *Rep Trans Devonshire Ass* **125**, 71-112 (with an appendix on the geology of the Whetstone Beds by R A Edwards)

Stanier, P 1985a 'Granite working in the Cheesewring area of Bodmin Moor, Cornwall' *Trevithick Society J* **12**, 36-51

Stanier, P 1985b 'The Granite Quarrying Industry in Devon and Cornwall: Part One 1800 -1910' *Industrial Archaeology Review* **8.2**, 171-89

Stanier, P 1985c *Quarries and Quarrying*. Princes Risborough: Shire

Stanier, P 1986a 'The Granite Quarrying Industry in Devon and Cornwall: Part Two 1910-85' *Industrial Archaeology Review* **9.1**, 7-23

Stanier, P 1986b 'John Freeman and The Cornish Granite Industry, 1840-1965' *Trevithick Society J* **13**, 7-35

Stanier, P 1987 'John Freeman and The Cornish Granite Industry: addendum' *Trevithick Society J* **14**, 93-6

Stanier, P 1989 *Dorset's Industrial Heritage*. Truro: Twelveheads Press

Stanier, P 1993 *Dorset Limekilns: a first survey*. DNHAS

Stanier, P 1995 *Quarries of England and Wales: An Historic Photographic record*. Truro: Twelveheads

Stanier, P 1996 'The Quarried Face: Evidence from Dorset's Cliffstone Quarries' *Mining History* **13.2** 1-9

Stanier, P 1998 *Mines of Cornwall and Devon*. Truro: Twelveheads

Stanier, P 1999 *South West Granite: A history of the Granite industry in Cornwall and Devon*. St Austell: Cornish Hillside

Stanier, P 2000 *Stone Quarry Landscapes*. Stroud: Tempus

Stanier, P 2015 *South West Stone Quarries: Building Stone Quarries in the West of England*. Truro: Twelveheads

Stanley, C C 1979 *Highlights in The History of Concrete*. Cement and Concrete Association

Stanley, C J and Vaughan, D J 1982 'Copper, lead, zinc and cobalt mineralization in the English Lake District: classification, conditions of formation and genesis' *J Geological Soc, London* **139**, 569-79

Stanley, L D 1843 *Alderley Edge and its Neighbourhood*. Macclesfield: Swinnerton (Republished 1972, Didsbury: E J Morten)

Stanley, M F 1990 'Carved in Bright Stone: Sources of Building Stone in Derbyshire' in D Parsons (ed) 1990a, 169-86

Stanton, W I and Clarke, A G 1984 'Cornish Miners at Charterhouse-on-Mendip' *Proc Univ Bristol Speleo Soc* **17.1**, 29-54

Stevenson, P 1969 'Tramways and Railways in the Nottingham Coalfield' *J Railway and Canal Historical Soc* **15**, 45-53

Stewart, R J 2005 *Ore Dressing at Devon Great Consols*. Tamar Mining Monograph No1. Calstock: Tamar Mining Press

Stewart, R J 2013 *Devon Great Consols: A Mine of Mines*. Camborne: The Trevithick Society

Stewart, R J 2014 'Firesetting in West Devon – an initial discussion' *Fifty years of Mine Exploration: Proceedings of the 2011 NAMHO Conference, Preston Montford, Shropshire*. Shropshire Caving and Mining Club, 111-14

Stocker, D and Everson, P 1990 'Rubbish Recycled: A Study of the Re-Use of Stone in Lincolnshire' in D Parsons (ed) 1990a, 83-101

Stocker, M 2007 *Kentish Ragstone*. Published privately

Stone, R 2007 *The Collieries and Coalminers of Staffordshire*. Chichester: Phillimore

Stone, J F S 1933 'A flint mine at Martin's Clump, Over Wallop' *Proc Hants Field Club and Arch Soc* **12**, 177-80

Straker, E 1969 *Wealden Iron*. Kelley, New York

Strassburger, M 2000 *Early Ochre-Mining in the Royal Forest of Dean, Gloucestershire*. Unpublished Mss

Stratton, M 1986 'The Terracotta Industry: its Distribution, Manufacturing Processes and Products' *Industrial Archaeology Review* **8.2**, 194-214

Stuckey, D 1965 *Adventurer's Slopes – the story of the silver and lead mines of Combe Martin in Devon. West Country Handbook No.7*. Bracknell: West Country Publications

Sturgess, J 2000 *California Quarry - Western Blackpit - Cornwall - Archaeological Assessment*. National Trust - Cornwall Archaeological Unit

Sunter, N and Woodward, P J 1987 *Romano-British Industries in Purbeck: Excavations at Norden, Ower and Rope Lake Hole*. DNHAS Monograph **6**. Dorchester: DNHAS

Supple, B 1987 *The History of the British Coal Industry Volume 4: 1914-1946: The Political Economy of Decline*. Oxford: University Press

Sutherland, D S 2003 *Northamptonshire Stone*. Wimborne: Dovecote Press

Sutherland, D S 2008 'Vernacular stone buildings in Northamptonshire' in P Doyle *et al* (eds) 2008, 58-61

Sutherland, D S 1990 'Burnt Stone in a Saxon Church and its Implications' in D Parsons (ed) 1990a, 102-113

Swift, G 1986 'Two Radio-carbon dates for Minepits at Sharpethorne Brickworks' *Wealden Iron* **2.6**, 54-55

Symons, J C 2003 *The Mining and Smelting of Copper in England and Wales, 1760-1820*. MPhil thesis, Coventry University in collaboration with University College Worcester [PDF document] http://eprints.worc.ac.uk/293/ [accessed 3 January 2013]

Tatler, S, Bellamy, P S, Broadbent, G and Hawkins, A 2009 *The Dorset Alum and Copperas Industries, Fieldwork on Brownsea Island, Interim Report*. On behalf of Poole Harbour Heritage Project Ltd (PHHP). Terrain Archaeology and English Heritage, Report **53287/2/2**

Tatton-Brown, T W T 1990 'Building Stone in Canterbury *c.*1070-1525' in D Parsons (ed) 1990a, 70-82

Tatton-Brown, T W T 2002 *The English Cathedral*. London: New Holland

Taylor, B J, Price, R H and Trotter, F M 1963 *Geology of the Country around Stockport and Knutsford*. Memoirs of the Geological Survey of Great Britain. London: HMSO

Taylor, E 1984 'Limekilns in Avon' *Bristol Industrial Archaeol J* **17**

Taylor, H 1999 *Hartington Moor Farm, Hartington Town and Middle Quarter, Derbyshire. Archaeological Survey,* Unpublished report

Taylor, H M and Taylor, J 1965 *Anglo Saxon Architecture*. Cambridge: University Press (2 vols)

Taylor, J 1799 'Sketch of the mining history of Devon and Cornwall' *Philosophical Magazine* **5**, 357-65

Taylor, J 1980 *Bronze Age Goldwork of the British Isles*. Cambridge: University Press

Taylor, M V and Collingwood, R G 1926 'Roman Britain in 1926' *J Roman Studies* **16**, 216-44

Taylor, S R 1983 'A stable isotope study of the Mercia Mudstones (Keuper Marl) and associated sulphate horizons in the English Midlands' *Sedimentology* **30.1**, 11-31

Taylor, S, Jones, A M and Young, T 2014 'Smelting Point: Archaeological Excavations along the route of the Avon water main renewal, Plympton, Devon 2009' *Proc Devon Archaeol Soc* **72**, 187-276

Taylor, W 2001 *South Yorkshire Pits*. Barnsley: Wharncliffe Books

Tebb, B and Smith, D H 2007 *George Stephenson's Crich Railway*. Crich: Crich Tramway Village

Tebbutt, C F and Cleere, H 1973 'A Romano-British Bloomery at Pippingford, Hartfield' *Sussex Archaeol Collections* **111**, 27-40

Temple, D 1994 *The Collieries of Durham*. Newcastle-upon-Tyne: Trade Union Printing

Thomas, A and B 1986 *History of Brayton Domain Collieries*.

Thomas, G and Fletcher, W 2001 'Prehistoric and Roman salt-making in the Lincolnshire Marsh' in S Ellis and H Chapman (eds) *The wetland heritage of the Lincolnshire Marsh: An Archaeological Survey*. Hull: Humber Wetlands Project, University of Hull, 215–30

Thomas, I A 1973 *Celestite*. Mineral Resources Consultative Committee, Mineral Dossier **6**. London: HMSO

Thomas, I A 1996 'The quarries and the slates' in T G Hughes (ed) 1996b, 1-24 and The Quarry Records and Annexes

Thomas, I A 1997(Oct) 'Set in stone' *Peak and Pennine*, 28-31

Thomas, I A 1999 *Tarmac's Derbyshire Heritage: Part I*. Tarmac Papers, 325-55. Tarmac Ltd History Initiative

Thomas, I A 2000 *Tarmac's Derbyshire Heritage: Part II*. Tarmac Papers. Tarmac Ltd History Initiative, 267-336

Thomas, I A 2006 'Southwell Minster' *Mercian Geologist* **16.3**, 220-2

Thomas, I A 2008 'Hopton Wood Stone - England's premier decorative stone' in P Doyle et al. (eds) 2008, 90-105

Thomas, I A 2009 *Safeguarding building stone resources*. Unpublished report by NSC for Derbyshire CC and English Heritage

Thomas, I A 2012 *The extractive industries in the Derwent Valley Mills World Heritage Site*. Derwent WISE, Lower Derwent landscape Partnership

Thomas, I A 2014 *The quarry industry in Wales – a history*. Wirksworth: National Stone Centre

Thomas, IA and Cooper, M 2008 'The Geology of Chatsworth House: A guide to the building stones, ornamental stones and mineral collections' *Mercian Geologist* **17,** 27-42

Thomas, J 1998a *Stone Quarrying: Building stone in Dorset*. Wimborne: Dovecote Press

Thomas, J 1998b *Stone Quarrying*. Wimborne: Dovecote Press, Discover Dorset series

Thomas, J 2008 *Dorset stone*. Wimborne: Dovecote Press

Thomas, N 1998 *Calstock lime kiln. An archaeological evaluation.* Cornwall HES Report **1998 R007**

Thomas, N 2000 *Waterwheel at Virginia China Clay Works - An Archaeological Survey*. Cornwall CC Report **2000R043**

Thomas, N 2002 *Greensplat Engine House, Carthew, Cornwall - Historic Building Record and Mitigation Survey.* Cornwall CC Report **2002 R020**

Thomas, N and Buck, C 1984 *A Rapid Identification Survey of Parishes adjoining the Tamar Valley, Cornwall*. CAU Report **1984R030**

Thompson, D B 1995 *A Guide to the History and Geology of Quarrying at localities along the Natural History Trail in Corbet Wood, Grinshill, North Shropshire*. Clive and Grinshill Conservation Committee

Thompson, E H 1965 *Roman Chester.* Chester: Grosvenor Museum

Thorburn, J A 1988 'Early Metallurgy in the Welsh Borders, 146-150' in J Ellis Jones (ed) *Aspects of Ancient Mining and Metallurgy: Acta of a British School at Athens Centenary Conference at Bangor.*

Thorndycraft, V R, Pirrie, D and Brown, A G 2004 'Alluvial Records of Medieval and Prehistoric Tin Mining on Dartmoor, Southwest England' *Geoarchaeology* **13.3**, *219-36*

Thornes, R 1994 *Images of Industry – Coal.* Abingdon: Taylor Francis

Timberlake, S 1990a 'Excavations at Parys Mountain and Nantyreira' in P Crew and S Crew (eds) 1990, 15–21

Timberlake, S 1996 'Ogof Llanymynech' *Archaeology in Wales* **36**

Timberlake, S 2002a 'Mining and prospection for metals in Early Bronze Age Britain, making claims within the archaeological landscape' in J Brück (ed) *Bronze Age Landscapes: Tradition and Transformation*, 179–92

Timberlake, S 2002b 'Ancient prospection for metals and modern prospection for ancient mines – the evidence for Bronze Age mining within the British Isles' in M Bartelheim, E Pernicka and R Krause (eds) *The Beginnings of Metallurgy in the Old World*. Forschungen zur Archaeometrie und Altertumswissenschaft **1**, Rahden, Westfalia: Institut fur Archaometrie, Freiberg, Verlag Marie Leidorf Gmbh, 327–58

Timberlake, S 2003 *Excavations on Copa Hill, Cwmystwyth (1986–1999): An Early Bronze Age copper mine within the uplands of Central Wales*. BAR British Series **348**. Oxford: Archaeopress

Timberlake, S 2004 'Early Leats and Hushing Remains: Suggestions and Disputes of Roman Mining and Prospection for Lead' *Mining History: Bull PDMHS* **15.4-5**, 64-82

Timberlake, S 2005a 'The archaeology of Alderley Edge and the North-East Cheshire hinterland' in S Timberlake and A Prag (eds)

Timberlake, S 2005b 'Stone Mining Tools from Alderley Edge' in S Timberlake and A Prag (eds)

Timberlake, S 2005c 'The experimental smelting of copper ores from Engine Vein' in Timberlake and Prag (eds)

Timberlake, S 2007 *An archaeological evaluation at Hamburg Way, King's Lynn.* CaAU report

Timberlake, S 2009a 'Copper mining and metal production at the beginning of the British Bronze Age' in P Clark (ed) *Bronze Age Connections*. Oxford: Oxbow, 956-1022

Timberlake, S 2009b 'The origins of metal mining in Britain: The exploration and archaeological excavations of the Early Mines Research Group in Central Wales' *Welsh Mines Society J* **1**

Timberlake, S 2010 *Cobalt Mining in the UK*. Presentation to the NAMHO Research Seminar, Carnforth (author's notes)

Timberlake, S, Burke, T, King, C and Pye, C 2005 'A topographical and archaeological landscape survey of the AELP Core Area of Alderley Edge, Cheshire, with additional reference to its hinterland'. *British Archaeological Reports* **396**, 124-68

Timberlake, S and Kidd, D 2005 'The archaeological excavation of a Roman mine shaft and gallery ('Pot Shaft') at Engine Vein, Alderley Edge' in S Timberlake and A Prag (eds)

Timberlake, S and King, C 2005 'Archaeological excavations at Engine Vein, Alderley Edge, 1997' in S Timberlake and A Prag (eds)

Timberlake, S and Mills, S J 2003 'The Use of a Portable XRF within an early nineteenth century cobalt mine' *UK Journal of Mines and Minerals* **23**, 41-46

Timberlake, S and Prag, A (eds) 2005 *The Archaeology of Alderley Edge – Survey, Excavation and Experiment in an Ancient Mining Landscape*. BAR British Series **396** Oxford: Archaeopress

Tindle, A G 2008 *Minerals of Britain and Ireland*. Harpenden: Terra Publishing

Todd, C and Laws, P 1972 *The Industrial Archaeology of Cornwall*. Newton Abbot: David and Charles

Todd, K R U 1950 'A Neolithic Flint Mine, East Horsley, Surrey' *Archaeol News* **2.9**, 144

Todd, M 1987 *The South-West to AD1000*. London: Longman

Todd, M 1996 'Ancient Mining on Mendip, Somerset: a Preliminary Report on Recent Work' *Mining History* **13.2**, 47-51

Todd, M 2007 *Roman Mining in Somerset. Excavations at Charterhouse on Mendip, 1993-1995*. Exeter: Mint

Tolson, J M, Roose, G and Whetmath, C F D 1974 *Railways of Looe and Caradon.* Bracknell: Forge Books

Tonks, E 1988-1992 *The Ironstone Quarries of the Midlands*. (9 vols) Cheltenham: Runpast

Tonks, E S 2007 *The Snailbeach District Railway*. The Industrial Railway Society (2nd edition)

Topping, P, Blood, K, Lofthouse, C and Bowden, M 1992 *RCHME: Greenside Survey.* RCHME AI report

Topping, P and Lynott, M (eds) 2005 *The Cultural Landscape of Prehistoric Mines*. Oxford: Oxbow

Town, M 2014 *Nenthead Mines, Nenthead, Cumbria: archaeological survey and management plan.* NAAL Report **13/13**

Trafford Wynne, T 1906-7 'Gypsum, and its occurrence in the Dove Valley' *Trans Institution of Mining Engineers* **32**, 171-192

Travis, J R 2008 *Coal in Roman Britain*. BAR British Series **468**. Oxford: Archaeopress

Trevarthen, M, Broadbent, G, Bellamy, P S and Hawkins, A 2009 *The Dorset Alum and Copperas Industries Studland Circles: Interim Report on Sample Excavation of Circle Sh10, September 2009*. Report on behalf of Poole Harbour Heritage Project Ltd (PHHP), Terrain Archaeology, and English Heritage, Report **53300/2/1**

Trevarthen, M, Bellamy, P S, Broadbent, G, Hawkins, A and Wilson, C 2010 *The Dorset Alum and Copperas Industries Interim Report on Excavations at Kimmeridge, May 2009*. Report on behalf of Poole Harbour Heritage Project Ltd (PHHP), Terrain Archaeology, and English Heritage, Report **53294/2/1**

Trimble, D 2001 'Excavations at an Early Roman Saltern in Moreton Fen, Lincolnshire' in T Lane and E L Morris 2001 (eds)

Trueman, M and Gill, M C 1990 *Snailbeach Lead Mine Stage II Study - Archaeological Survey.* LUAU report

Tuck, J T 1993 *Collieries of Northumberland: Volume 1, Newcastle upon Tyne*. TUPS

Tucker, D G 1977 'Millstones, Quarries, and Millstone-Makers' *Post Medieval Archaeol* **2**, 1-21

Tucker, D G 1985 'Millstone making in the Peak District of Derbyshire: The quarries and the technology' *Industrial Archaeology Review* **8.1**, 42-58

Tucker, D G 1987 'Millstone Making in England' *Industrial Archaeology Review* **9.2**, 167-188

Tuffs, P 1997 *Catalogue of Cleveland Ironstone Mines.* Cleveland Ironstone Series. Guisborough: Peter Tuffs

Turnbull, L 2006 *The History of Lead Mining in the North East of England*. London: Ergo

Tylecote, R F 1965 'Iron smelting in pre-industrial communities' *J Iron and Steel Institute* **203**, 340-48

Tylecote, R F 1967 *'The bloomery site at West Runton, Norfolk' Norfolk Archaeology* **34**, 187-214

Tylecote, R F 1983 'Scottish Antimony' *Proc Soc Antiquaries of Scotland* **113**, 645-46

Tylecote, R F 1986 *The Prehistory of Metallurgy in the British Isles*. London: The Institute of Metals

Tylecote, R F 1992, *A History of Metallurgy*. London: The Institute of Materials

Tylecote, R F, Photos, E and Earl, B 1989 'The composition of tin slags from the south-west of England' *World Archaeology* **20.3**, 435-45

Tyler, A W 1982 *Prehistoric and Roman Mining for Metals in England and Wales.* Unpublished PhD thesis, University of Wales, Cardiff

Tyler, I 1990 *Force Crag. The History of a Lakeland Mine*. Ulverston: Red Earth Publications

Tyler, I 1994 *Honister Slate: The History of a Lakeland Slate Mine*. Cumbria: Blue Rock Publications

Tyler, I 1995 *Seathwaite Wad and the Mines of The Borrowdale Valley*. Ulverstone: Red Earth

Tyler, I 1989 *Cockley Beck and Seathwaite Mines*. Ulverstone: Red Earth

Tyler, I 1992 *Greenside: A tale of Lakeland Mines*. Ulverstone: Red Earth

Tyler, I 2000 *Gypsum in Cumbria*. Keswick: Bluerock Publications

Tyler, I 2005 *Goldscope and the Mines of Derwent Fells*. Keswick: Blue Rock Publications

Tyler, I 2009 *Roughton Gill and the Mines of the Caldbeck Fells*. Keswick: Blue Rock Publications

Tyson, L O 1989 *A History of the Manor and Lead Mines of Marrick, Swaledale.* British Mining Monograph **38**

Tyson, L O 1995b *The Grinton Mines*. British Mining Monograph **51**

Tyson, L O 1995b *The Arkengarthdale Mines*. British Mining Monograph **53**

Tyson, L O 2007 *Mashamshire Collieries*. British Mining Monograph **82**

Tyson, L O (forthcoming) *Collieries in the Tan Hill area.*

Tweddell, C M 1876 *Furness past and present: its history and antiquities*. Barrow-in-Furness: Richardson

Ullathorne, A 2002 *Hollow Farm, Harthill and Youlgreave, Derbyshire*. PDNPA report

Ussher, W A E 1933 *The Geology of the Country around Torquay.* London: HMSO

Various 2005 *The Cannock Chase Coalfield and its Coal Mines*. Cannock Chase Mining Historical Society

Vernon, R W 1998 *Second Interim Report on Geophysical Surveys at the Ellastone Copper Smelt Mill Site, Staffordshire.* Unpublished report, Dept of Archaeological Science, University of Bradford

Vernon, R W 2000 in Porter, L and Robey, J 2000 *The Copper and Lead Mines Around the Manifold Valley, Staffordshire*. Ashbourne: Landmark

Vernon, R W 2008 'Alfred Williams, Leo Daft and "The Electrical Ore-Finding Company Limited"' *British Mining Memoirs* **86**, 4-30

Vernon, R W, McDonnell, G and Schmidt, A 1998a 'The geophysical evaluation of an ironworking complex: Rievaulx and environs, North Yorkshire' *Archaeological Prospection* **5**, 181-201

Vernon, R W, McDonnell, G and Schmidt, A 1998b 'An integrated geophysical and analytical appraisal of early iron working: three case studies' *Historical Metallurgy* **32.2**, 67-81

Vernon, R W, McDonnell, G and Schmidt, A 2002 'The Geophysical Evaluation of British Lead and Copper Working Sites. Comparison with Iron Working' *Archaeological Prospection* **9.3**, 123-34

Vickers, N 1987 'The Structure of the Whitby Jet Industry in 1871' *Local Population Studies* **38**, 8-17 [Web document] www.localpopulationstudies.org.uk/pdf/lps38/lps38_1987_8-17.pdf [accessed 3 January 2015]

Waddington, C 2004 *The Joy of Flint: Introduction of Stone Tools and Guide to the Museum of Antiquities Collection*. Museum of Antiquities, University of Newcastle-upon-Tyne

Wade, E A 1982 *The Redlake Tramway and China Clay Works*. Truro: Twelveheads Press

Wagner, G A and Weisgerber, G 1985 *Silber, Blei und Gold auf Sifnos*. Bochum: Deutches, Bergbaumuseum

Wagner, G A and Weisgerber, G 1988 *Antike Rdel- ynd Buntmetalgewinning auf Thoasos*. Bochum: Deutches Bergbaumuseum

Wain, K 2014 *The Coal Mining Industry of Sheffield and North East Derbyshire*. Stroud: Amberly

Wainwright, G J and Bowen, H C 1979 *Gussage All Saints; A Dark Age settlement in Dorset.* DoE Archaeological Report **10**. London: HMSO

Walkden, G 2015 *Devonshire marbles: their geology, history and uses. Volume 1 Understanding the marbles*. Geologists' Association Guide **72**. London

Walkden, G 2015 *Devonshire marbles: their geology, history and uses. Volume 2 Recognising the marbles*. Geologists' Association Guide **72**. London

Wallace, W 1890 *Alston Moor: Its Pastoral People, its Mines and Miners*. Newcastle-upon-Tyne: Davis Books, (1986 reprint)

Wallis, H 2007 *Archaeological Evaluation at the site of Caister Brick Pits, Caister-on-Sea, Norfolk*. [PDF document] http://archaeologydataservice.ac.uk/archives/view/greylit/details.cfm?id=29488 [accessed 4 March 2012]

Wallwork, K L 1959 'Mid-Cheshire Salt Industry' *Geography* **44.205**, Pt.3, 171-86

Waltham, T 1992 'The Sandstone Caves of Nottingham' *Mercian Geologist* **17**, 129

Waltham, T 1994 'The Sand Mines of Nottingham' *Bull PDMHS* **13.4**, 1-11

Waltham, T 2001 'The explosion crater at Fauld' *Mercian Geologist* **15.2**, 123-125

Walton, J 1940(Aug) 'Bakestone quarrying: an historic Yorkshire quarrying industry' *Quarry Managers' J*, 121-2

Ward, T 1900 'The subsidence in and around Northwich in Cheshire' *Trans Institution of Mining Engineers* **19**, 241-64

Warland, E G 1941 *Modern practical masonry*. London: Pitman (2nd edition, 1953)

Warnes, A R 1926 *Building Stones Their Properties, Decay and Preservation*. London: Benn

Warriner, D, Willies, L and Flindall, R 1981 'Ringing Rake and Masson Soughs and the mines on the east side of Masson Hill, Matlock' *Bull PDMHS* **8.3**, 65-100

Warrington, G 1965 'The metalliferous mining district of Alderley Edge, Cheshire' *Mercian Geologist* **1.2**, 111-29

Warrington, G 1974a 'Les evaporites du Trias britannique' *Bulletin de la Societé Géologique de France* **16.6**, 708-23

Warrington, G 1974b 'Trias' in D H Rayner and J E Hemingway (eds) *The Geology and Mineral Resources of Yorkshire*. Yorkshire Geological Society, 145-60

Warrington, G 1980a 'The Alderley Edge mining district' *Amateur Geologist* **8**, 4-13

Warrington, G 1980b 'Non-ferrous mining in north Shropshire and Cheshire' *SCMC J 1979*, 9-20

Warrington, G 1981a 'The copper mines of Alderley Edge and Mottram St. Andrew, Cheshire' *J Chester Archaeol Soc* **64**, 47-73

Warrington, G 1981b 'The British Copper Company Limited (1864-1882)' *SCMC J 1980*, 9-10

Warrington, G 1995 'North Shropshire Copper Mines' in A Pearce (ed) 1995 *Mining in Shropshire*. Shrewsbury: Shropshire Books

Warrington, G 2010 'Alderley Edge district, Cheshire' in Bevins, R E, Young B, Mason, J S, Manning, D A C and Symes, R F (eds) *Mineralization of England and Wales. Geological Conservation Review Series* **36**. Peterborough: Joint Nature Conservation Committee, 182-190

Warrington, G 2012a 'The legacy of mining at Alderley Edge' *Mercian Geologist* **18** (1), 75-76.

Warrington, G 2012b 'Mineralization in the Triassic rocks of the Cheshire Basin with particular reference to Alderley Edge, Cheshire, and Clive, Shropshire' *Proc Shropshire Geological Soc* **17**, 33-39

Warrington, G 2016 'Mining in the Alderley district: the documented period' in A J N W Prag 2016 (ed) *Living with the Edge: Alderley's Story*. Manchester: University Press

Warrington, G 2013 'Former workings in Jurassic ironstone near Grantham' *Mercian Geologist* **18.2**, 128-32

Watcher, J S 1995 *The towns of Roman Britain*. London: Routledge

Waterhouse, R (forthcoming) *The Archaeology of the Tavistock Canal.*

Waterhouse, R 2008a Plan of Morwellham Manganese Mill, deposited with Devon County HER

Waterhouse, R 2008b Plan of Shillamill Manganese Mill, deposited with Devon County HER

Waterhouse, R 2012 'Tavistock Canal: Surveying a Forgotton marvel of the Industrial Age' *Current Archaeology* Dec 2012, 34-40

Waters, C N, Northmere, K, Prince, G, Bunton, S, Butcher, A, Highley, D E, Lawrence, D J D and Snee, C P M 1996 *A geological background for planning and development in the City of Bradford Metropolitan District.* BGS Technical Report **WA 96.1**

Watney, B 1963 *English Blue and White Porcelain of the 18th Century*. London: Faber and Faber

Watson, B 2013 'The Princess in the Police Station' *British Archaeology,* May-June 2013, 20-23

Watson, M and Musson, C 1996 *Shropshire from the Air An English County at Work*. Shrewsbury: Shropshire Books

Watson, J Y 1843 *A Compendium of British Mining.* London: published privately

Webb, B and Gordon, D A 1978 *Lord Carlisle's Railways.* Leicester: Railway Correspondence and Travel Society

Webster, C (ed) 2008 *The Archaeology of South West England. South-west Archaeological Research Framework: Resource Assessment and Research Agenda.* Taunton: Somerset County Council

Webster, G 1952 'The Lead-Mining Industry in North Wales in Roman Times' *Flintshire Historical Society Publication* **13**, 5-33

Wells, L 2005 *Underground at Stanton: A Brief History of the first Twenty Years of Winn's Underground Ironstone Mine, 1938-1958*. Scunthorpe: published privately

Wessex Archaeology 2004 *Rapid Coastal Zone Assessment Survey Phase I, Dorset Coast Historic Environment Research Framework.* (draft)

West, I, 2014 *Geology of the Wessex Coast of Southern England: Kimmeridge - the Blackstone - Oil Shale.* [Web document] www.southampton.ac.uk/~imw/Kimmeridge-Oil-Shale.htm [accessed 12 December 2015]

Wharmby, P 1987 *A report on the rocksalt mines and brine shafts in the Cheshire saltfield*. Cheshire County Council

Wheeler, R E M and Wheeler, T V 1932 *The Lydney Excavations*. Oxford

White, A W A 1970 *Men and Mining in Warwickshire*. Historical Society, Coventry Branch

White, R 2000 'The Roman Lead-workings in Linley' in J Leonard et al. (eds) *The Gale of Life. Two thousand years in South-West Shropshire*. Logaston Press, 31-41

White, R 2006 Aspects of the management of the remains of the limestone industry of the Yorkshire Dales. *Industrial Archaeology Review* **28.2,** 107-15

White, R F 1977 'A Roman lime kiln near Cardington Mill Bedford' *Bedfordshire Archaeol* **12**, 23-26

White, R F 1989 'Conservation of the Remains of the Lead Industry in the Yorkshire Dales' *Industrial Archaeology Review* **12.1**, 91-104

White, R F 1995 'A Landscape of the Lead Industry: The Yorkshire Dales' in M Palmer and P Neaverson (eds) *Managing the Industrial Heritage*. Leicester: University of Leicester

Whittaker, A 1970 'The salt industry at Puriton, Somerset' *Somerset Archaeol Natur Hist* **114**, 96-99

Wilcock, D 1998 *Teesdale lime kiln survey.* Unpublished report

Wild, C 2000 *Saltom Pit, Whitehaven: archaeological fabric survey*. LUAU report

Wildgoose, P 1993 *The Forest of Dean as a Major Centre of the iron industry from Roman to medieval times*. Unpublished thesis

Wilkie, I and Burt, R 1984 'Manganese Mining in the South-West of England' *J Trevithick Soc* **11**, 18-40

Wilkinson, A 2010 *Hemerdon Mine, Plympton, Devon: Archaeological Watching Brief*. Cornwall HES Report **10152**

Wilkinson, M 1992 'A field survey of lime-kilns in the Forest of Dean: part 1 – a concise history of lime-burning' *Dean Archaeol* **5**, 37-49

Williams, C 2010 *The River Ran Red.* Published privately

Williams, D F 1991 *Quernstones and honestones from the Romano-British site at Boxfield Farm, Stevenage, Hertfordshire*. Ancient Mons Lab Report **29.91**

Williams, D W 1983 'Islamic Glass Vessel Fragments from the Old Vicarage, Reigate, Surrey' *Medieval Archaeol* **27**, 143-46

Williams, J 1810 *The Natural History of the Mineral Kingdom*. Edinburgh (2nd edition)

Williams, J H 1971a 'Roman Building Materials in South-East England' *Britannia* **2**, 166-195

Williams, J H 1971b 'Roman Building Materials in the South-West' *Trans Bristol and Gloucestersire Archaeol Soc* **90**, 95-119

Williams, M and Reid, M 2008 *Salt: Life and Industry: Excavations at King Street, Middlewich, Cheshire*. BAR British Series **456.** Oxford: Archaeopress

Williams, P 2005 *Images of Yorkshire Coal.* Ashbourne: Landmark

Williams, R 2004 *Lime kilns and lime*. Aylesbury: Shire

Williams, R G J 1998 'The St Cuthbert's Roman Mining Settlement, Priddy, Somerset: Aerial Photographic Recognition' *Proc Univ Bristol Speleo Soc* **21.2**, 123-32

Williamson, I 1963 'The Anglezarke Lead Mine' *Mining Magazine* **108**, 133-9

Williamson, I A 1999 'The Burnley Coalfield: Some geological influences upon the former mining exploitation and present-day development' *British Mining Memoirs* **63**, 5-27

Willies, L M 1969 'Cupola Lead Smelting Sites in Derbyshire, 1737 to 1900' *Bull PDMHS* **4.1**

Willies, L M 1975 'The Washing of Lead Ore in Derbyshire during the Nineteenth Century' *Bull PDMHS* **6.2**, 53-64

Willies, L M 1977 'The Recovery of the Wills Founder Water Pressure Engine' *Bull PDMHS* **6.5,** 180-90

Willies, L 1982 *Lead and Leadmining*. Aylesbury: Shire

Willies, L M 1990 'Derbyshire Lead Smelting in the Eighteenth and Nineteenth Centuries' *Bull PDMHS* **11.1**, 1-19

Willies, L M 1991 'Lead: Ore Preparation and Smelting' in J Day R F Tylecote (eds) *The Industrial Revolution in Metals*. London: The Institute of Metals

Willies, L M 1992 'Problems in the interpretation of cupola lead smelting sites' in L Willies and D Cranstone (eds) 1992, 40-2

Willies, L M 1994 'Firesetting Technology' in T D Ford and L Willies (eds) 1994, 1-8

Willies, L M 1997a 'Roman Mining at Rio Tinto, Huelva, Spain' *Mining History: Bull PDMHS* **13.3**, 1-29

Willies, L M 1997b 'Ironstone Mining in Derbyshire' *Mining History: Bull PDMHS* **13.4**, 1-11

Willies, L M 1998 'Washing Floors at Winster Pitts, Derbyshire' *Mining History: Bull PDMHS* **13.6**, 49-57

Willies, L M 2004 'Water Power in Peak District Mining' in P Claughton (ed) 2004, 36-42

Willies, L M 2009 'Bole Lead Smelting Technology and the Linch Clough (Derbyshire) bole' *Historical Metallurgy* **43**, 19-32

Willies, L and Cranstone, D (eds) 1992 *Boles and Smeltmills: report of a seminar on the history and archaeology of lead smelting held at Reeth, Yorkshire, 15-17 May 1992*. Historical Metallurgy Society

Willies, L, Gregory, K and Parker, H M 1989 *Mill Close – The Mine that Drowned.* Cromford: Scarthin Books and PDMHS

Willies, L M, Rieuwerts, J H and Flindall, R F 1977 'Wind, Water and Steam Power on Derbyshire Lead Mines: A List' *Bull PDMHS* **6.6**, 303-20

Willies, L, Redvers-Higgins, N and Wain, I 2011 *'Finished Labour of a Thousand Hands': The Archaeology of the Combe Down Stone Mines, Bath, Somerset*. Oxford: Oxford Archaeology

Willies, L M, Roche, V S, Workley, N E and Ford, T D 1987 *The History of Magpie Mine, Sheldon, Derbyshire*. PDMHS Special Publication **3**

Wilson, A A 1990 'The Mercia Mudstone Group (Trias) of the East Irish Sea Basin' *Proc Yorks Geological Soc* **48.1**, 1-22

Wilson, A A and Evans, W B 1990 *Geology of the country around Blackpool*. Memoir of the British Geological Survey, Sheet **66**. London: HMSO

Wilson, D 1947 *Dolomite and refractories by Steetley.* Worksop: Steetley Co Ltd

Wilson-North, R 1996 'Recording the Iron Mines of Exmoor' *Mining History: Bull PDMHS* **13.2**, 137-42

Windley, B F 1995 *The Evolving Continents*. Chichester: Wiley (3rd edition)

Wood, C (ed) 2003 *Stone Roofing: Conserving the materials and practice of traditional stone slate roofing in England*. English Heritage Research Transactions **9**

Wood, E S 1951 'Neolithic Sites in West Surrey (with a note on a medieval flint mine at East Horsley)' *Surrey Archaeol Collects* **52**, 11-28

Wood, O 1988 *West Cumberland Coal 1600-1983.* CWAAS Extra Series **24**

Woodiwiss, S (ed) 1992 *Iron Age and Roman salt production and the Medieval town of Droitwich*. CBA Research Report **81**

Woods, P J E 1973 'The geology of Boulby Mine' *Economic Geology* **74.2**, 409-18

Woore, S 2002 *The limekilns, Turnditch, Derbyshire.* Unpublished notes in Derbyshire HER

Worley, N E 2005 'The occurrence of halite in the Permian A Bed Evaporite, Kirkby Thore, Cumbria' *Proc Yorks Geological Soc* **55.3**, 199-203

Worley, N E and Ford, T D 1977 'Mississippi Valley type orefields in Britain' *Bull PDMHS* **6.2**, 201-8

Worth, R N 1875 'Economic Geology of Devon' *Rep Trans Devonshire Ass* **7**, 209

Worth, R N 1910 'The Stannaries' *Trans Plymouth Institution* **15**, 21-45

Worth, R H 1953 *Worth's Dartmoor*. Edited by G M Spooner and R S Russell. Newton Abbot: David and Charles

Wright, M E 1988 'Beehive quern manufacture in the south-east Pennines' *Scottish Archaeological Review* **5.1 & 2**, 65-77

Wright, T 1862 'Roman Mining Operations on the Borders of Wales' *Intellectual Observer*, 295-309

Yates, J 1858 'Mining Operations of the Romans' *Somerset Archaeol Natur Hist* **8**, 1-34

Yates, T, Lott, G K and Jefferson, D 2006-7 *Conserving stone buildings – pilot study into methods of establishing the sources, uses and potential to obtain authentic stone for building conservation*. Report for English Heritage

Youles, T 2003 'Delving In Dean: The Delves. An Area Of Unrecorded Early Coal Mining' *J Gloucestershire Soc for Industrial Archaeol,* 31-5

Youles, T 2004 'Delving In Dean: The Delves. An Area Of Unrecorded Early Coal Mining (Part Two)' *J Gloucestershire Soc for Industrial Archaeol,* 3-11

Youles, T, Fernando, P, Burton, T and Colls, F 2008 ' Delving in the Dean: The Delves An Area Of Unrecorded Early Coal Mining (Part Three)' *J Gloucestershire Soc for Industrial Archaeol* 37-52

Zell, M 1994 *Industry in the Countryside: Wealden society in the sixteenth century*. Cambridge: University Press

Index

C

D

E

F

M

N

O

P

S

T

X

Y

Z

This publication presents the evidence collected in the first part of a Research Framework for the Archaeology of the Extractive Industries in England. The research has been carried out by the National Association of Mining History Organisations and draws primarily on expertise within the voluntary sector. It has been part funded by Historic England. The work represents the first attempt at such a comprehensive assessment of the historic extractive industries in England and the opportunity was taken to carry out an in-depth study of the available resources, using published material, before moving on to examine the current state of archaeological investigation. In doing so it brings together current knowledge on a wide range of issues, the geological context, the technologies used, the infrastructure of the industries, including the impact on transport links and settlement. It also examines historical, document based research and the results of archaeological investigation, not just for the extraction (mining or quarrying) of the minerals but their preparation and processing where it was carried out on or close to the extraction site.

As a result of the assessments, gaps have been revealed in current knowledge on all aspects of past mining and quarrying. Using the available archaeological resources and the historical evidence, the potential for new or further investigations has been identified and these are presented as a Research Agenda with a series of research aims across a wide range of themes.

The results of this first part of the Research Framework will be used to develop priorities for further investigation. It also provides information that will assist in forming future conservation and research strategies, and help to raise general awareness of the significance of the extractive industries as a cultural resource.

NAMHO

Historic England