15: Archaeological Science Techniques

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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 report the available techniques have been broadly grouped into four areas: dating, location and recording, characterisation, environmental. It must be stressed 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 now 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 case study below) 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 and 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 successfully been employed 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 amount of time elapsed from 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. The intensity of this light
can be correlated to the time elapsed since the sample was last heated or exposed to strong sunlight. 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 may prove useful at ancient quarries or opencasts.

Image – the site of firesetting at Old Hen mine, potentially dateable charcoal may be found in the debris at the base of the fired area. Photograph by Adam Russell

### 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 suggested 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 and 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 and increasing in use towards the middle of the 17th century but declining fairly rapidly around the end of that century at about the time that gunpowder was generally adopted for rock breakage.

### 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 find 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, and 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.

Where it is desired to quantify the amount of a specific element in a sample, Atomic Absorption Spectroscopy (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 that this can be done with, 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, firstly the likelihood of recycling and intermixing of lead from different origins, and more pertinently for England, the relative ratios of the lead 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- (Deaulty, 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 (Mike Gill pers comm). Similarly, evidence of early smelting in Derbyshire has been found in stream sediments (Kiernan and 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 fell away 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.

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).

Image – the metallophyte plant Spring Sandwort is commonly known as Leadwort due to its frequent presence on former lead-mining sites. Photograph by Adam Russell

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 such a 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. Through prehistory and the Roman period, although there were periods 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 remotely 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 2008).

Magnetometry measures the magnetic susceptibility of the earth directly beneath the instrument, and like conductivity sensors the instrument does 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, 1998b).

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.

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 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 plantation 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 for 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).

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 to 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 devices makes this easily available to anyone wishing to undertake fieldwork for recording spatial data to 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 case study). One of the earliest successes with this technique was at Grimes Graves flint mines in Norfolk, where an extensive programme of underground laser scanning resulted in a detailed high-res 3D image. This has enabled virtual tours of parts of underground sections where the public are not usually able to visit for safety reasons: this is available online at http://www.see3d.co.uk/node/81.

Scanning digital cameras, which build up a composite image from multiple exposures, also 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 as both 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.

image - 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 copyright of the Derbyshire Record Office and Google, overlaid by Adam Russell.

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 cover over 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 then be transferred on to resin board, enabling public display of the graffiti (Willies et al 2011 p.16-17).
15.6 Discussion

Most scientific techniques used by archaeologists require specialist equipment and expertise which will either be found in academic settings or commercial archaeological units and laboratories, whereas 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 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.