



The Archaeology of Mining and Quarrying in England

A Research Framework

**Resource Assessment
and
Research Agenda**

The Archaeology of Mining and Quarrying in England

A Research Framework for the Archaeology of the
Extractive Industries in England

Resource Assessment and Research Agenda

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Steering committee meetings were held at a number of venues, including the Peak District Mining Museum, at Matlock Bath, the National Stone Centre at Wirksworth and the Dales Countryside Museum at Hawes. We are also grateful to the New Inn, Mayhill, South Gloucestershire for the provision of facilities and to Derek Giles (Wheal Martyn) and Colin Buck (Cornwall CC) for facilitating meetings in Cornwall.

Regional seminars were held at Caphouse, Carnforth, Gunnislake, Snibston, Truro, Wirksworth, St Austell. At these seminars, talks on aspects of mine and quarry research were presented by Stewart Ainsworth, John Barnatt, Lee Bray, Ivor Brown, Simon Chapman, Mike Gill, Fred Hartley, David Johnson, Phil Newman, David Pybus, Peter Stanier, Ian Thomas, Simon Timberlake, Robert Waterhouse.

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This group represented a good cross-section, including curatorial and research-based professionals, as well as independent researchers. The lively debates that occurred made a major contribution in the formulation of the Research Agenda (see Section 16). Particular thanks go to those who provided presentations on aspects of mine and quarry historical and archaeological research, and to Bob Croft (Sidcot) and Professor Marilyn Palmer (Caphouse) who chaired the afternoon debates.

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Jon Humble: a tribute

Peter Cloughton, with substantial contributions from John Barnatt, Ian Thomas, Robert Waterhouse and Dave Williams

Jon Humble was integral to the instigation and development of this Research Framework. As explained below (Section 1.2), he was the initial contact between NAMHO and English Heritage, and he was closely involved with the project until illness caused his withdrawal early in 2015. Regrettably he died suddenly on 30 November 2015, at the age of 57.

He played a strategic role in mine conservation as English Heritage's (now Historic England's) Senior National Minerals Advisor, having been an Inspector of Ancient Monuments in the East Midlands since the late 1990s. Using his ability to bring together the various elements in the minerals industry and heritage interests, and his long-standing connections with the voluntary sector, mining history and mine exploration, he provided essential guidance as a member of our project steering group. Jon was a unique archaeologist.

All those who knew Jon recall a common theme - variously described as his 'modest eccentricities', 'often wickedly non-corporate', his 'joviality' and his sense of humour - he was fun to work with, be it on underground exploration, excavation, or in a project planning meeting. His involvement in the gestation of this Framework publication was always with a light touch.

However, as John Barnatt notes, Jon of course could be astutely professional. For example, he was instrumental, as one of the key partners, in setting up the restorations of Batemans's House and the Mandale Engine House in Lathkill Dale, Derbyshire, and for the commissioning of an archaeological survey of the dale. Similarly, he helped Peak National Park staff bring 'The Lead Legacy' assessment to fruition, again as a key player on the steering group that arranged the publication of the results and that worked behind the scenes to foster conservation of individual sites. He also took a lead role in Historic England's commissioning of the 2015 detailed report on the nature of underground mining remains and the scope for designation. At his death Jon was part way to arranging for Historic England to curate Paul Deakin's photographic archive and publish a book of Paul's images; his friends will now take this up and hopefully make it happen. Jon also worked with people from the mineral industry on heritage matters and was well respected because of his passion for the subject.

Ian Thomas speaks for many when he says that Jon was unique in bridging the gap between the minerals industry and heritage interests. In this particular respect Jon was a long-standing member of the UK Minerals Forum, a large liaison group engaging government and its agencies with all sectors of the extractive industry and environmental bodies. Jon assumed the task of collating and tabling regular environmental updates on behalf of all in that sector, to each Forum meeting. Similarly he was active in the English Stone Forum, again combining industry (extraction, specifying and processing), academia, professionals and conservation interests. He was always constructive and could be relied upon to lighten up proceedings (but still retaining professionalism), when matters were heading to 'nerdism'.

He was instrumental in organising the highly popular annual Derbyshire Archaeology Day and was a most welcome supporter of the National Stone Centre. Almost single-handedly he pulled together a previously disparate range of EH/HE policy stances involving minerals and heritage aspects (see English Heritage 2008, *Mineral Extraction and the Historic Environment*) and, as a result was highly respected by many potential or hitherto conflicting groups. This was strongly reflected in the broad cross section of interests represented at high level at Jon's funeral. Despite his high profile, he was always modest in his actions.

Others, like Dave Williams, will recall his personal, non-corporate side - being involved in expeditions to various places around the country to look at mining sites and to sample the beer. One of his eccentricities was a dislike of driving on motorways, so that on occasion it took a great deal of time to arrive at the destination. His use of a gadget given to him by English Heritage to locate monuments also caused some 'interesting' routes to be followed. On these trips there was usually some new gadget or toy, most of which seemed to be in lurid colours. Probably the most interesting of these trips was one to the Forest of Dean to look at iron mines, and in particular, fire-setting remains

in Bow Iron Mine. This was guided by a local expert (who should perhaps remain nameless), and the incredulity with which Jon regarded him and his foibles was entertaining.

Over the years, Jon was instrumental in bringing to fruition a number of important projects within mining and quarrying heritage, and he sowed the seeds of some yet to be completed, such as the protective designation for 'Heritage Quarries' and 'The Subterranean Industrial Legacy'. It is sad that Jon did not live to see this particular project 'The Research Framework for the Archaeology of the Extractive Industries in England' through to publication. What you read in the following pages will nevertheless stand as a memorial to his work in guiding us over the last decade and, given the time it has taken, we are left to speculate on the jokes he may have made at the launch. But we can all imagine the smile on his, and our faces as we do so.



Jon Humble at Parys Mountain – an image he evidently liked, as he used it in the title slide of his presentation, Fathoming New Approaches to the Subterranean Archaeological Resource, given to the Landscape Survey Group at Sheffield University in September 2014 (Jon Humble collection).

Foreword

This publication presents the evidence collected in the first part of a Research Framework for the Archaeology of the Extractive Industries in England, carried out by the National Association of Mining History Organisations, partially funded by Historic England (formerly English Heritage) and drawing primarily on expertise within the voluntary sector. It is the first time such a comprehensive assessment of the historic extractive industries has been attempted 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 background, the technologies used, the infrastructure of the industries, including the impact on transport links and settlement. It also examines historical, document based research and our knowledge of the industries based on 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.

The Resource Assessments are intended to be read collectively or individually. They begin chronologically, covering the prehistoric periods through to the end of Roman occupation. Thereafter, each mineral category is dealt with separately - bulk minerals, coal, iron, clay, lead, including silver and zinc, tin, copper, gold, gangue minerals and pigments, the minor metals, and then salt and the other evaporites. These are followed by two specialist assessments examining underground archaeology and the application of archaeological science to the study of the extractive industries.

Using the Historic Environment Records (HERs) as a starting point provided an overall picture for archaeological investigation, which revealed an imbalance across the country with some aspects of the extractive archaeology having a higher profile. The subsequent assessments also noted marked imbalances in the published historical material, which is dominated by coal and the non-ferrous metals. Archaeological investigation, much of it unpublished, has also revealed an imbalance in favour of the non-ferrous metals, with little effective investigation for coal or the bulk mineral (quarrying) industries. Investigation of iron production is notable in that it focuses almost entirely on the processing (smelting) rather than the extraction (mining) of its ores.

As a result of the assessments, gaps have been revealed in our 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. These include not only those specific to particular minerals but others with cross-cutting priorities, including methodology and the need for increased training and capacity building in higher education to provide archaeologists with the working knowledge to investigate the extractive industries.

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.

Dr Peter Cloughton MClfA - Project Director

Resumé

Cette publication présente les premiers résultats obtenus dans le cadre de la Recherche pour l'Archéologie des Industries Extractives en Angleterre, effectuées par la National Association of Mining History, organisation fondée en partie par l'Historic England (anciennement English Heritage) dans le but principal d'une expertise au sein du secteur bénévole.

C'est la première fois que l'on mène une telle recherche sur l'histoire de l'exploitation minière, et cela a été l'occasion d'évaluer, en détail, toutes les données disponibles, en faisant appel d'abord, à des documents publiés, avant d'examiner l'état des fouilles archéologiques. A cet égard, cette publication rassemble les connaissances actuelles sur un large éventail de questions, le contexte géologique, les technologies utilisées, l'infrastructure de l'industrie, y compris l'impact sur les liens et le règlement de transport. Elle examine également, à partir de documents fondés sur la recherche historique et notre connaissance de l'industrie basée sur la recherche archéologique, non seulement l'extraction (les mines ou les carrières) des minéraux, mais leur élaboration et leur traitement réalisés à l'endroit ou proche des lieux d'extraction.

On peut accéder à l'analyse des données, soit en lisant les chapitres individuellement, soit en lisant ensemble. Les données sont organisées par ordre chronologique, depuis la préhistoire jusqu'à la fin de l'occupation romaine. Ensuite, chaque catégorie de minerai est traitée séparément- le minerai en vrac, le charbon, le fer, l'argile, le plomb, notamment l'argent, et le zinc, l'étain, le cuivre, l'or, les gangues et les pigments, les métaux mineurs, et puis le sel et les autres évaporites. Cette analyse est suivie de deux autres spécialisées en archéologie souterraine et dans l'application de la science archéologique à l'étude des industries extractives.

Avec l'Historic Environment Records (HER) comme point de départ, un déséquilibre est apparu concernant l'état des recherches archéologiques dans le pays, certains aspects de l'archéologie extractive étant plus importants que d'autres.

Les analyses suivantes témoignent de déséquilibres évidents dans la publication de documents historiques, qui concernent surtout le charbon et les métaux non-ferreux. De la même façon, la recherche archéologique, pour l'essentiel inédite, confirme ce déséquilibre en faveur des métaux non-ferreux et peu d'investigations sur les industries du charbon et les autres minéraux.

La recherche sur la production du fer est dominée, pour l'essentiel, par la fusion et non l'extraction du minerai.

Ces études montrent qu'il subsiste des lacunes, en matière de connaissance, pour ce qui concerne l'ensemble des aspects de l'histoire des industries extractives.

Par conséquent, à partir des données archéologiques disponibles et des connaissances historiques, de nouvelles investigations ont été identifiées et sont présentées comme un programme de recherche dans le cadre du Research Agenda, avec un large éventail de thèmes. Ceux-ci comprennent non seulement ceux spécifiques aux minéraux particuliers, mais d'autres avec des priorités transversales, comme les questions de méthodologie ou le renforcement des formations dans l'enseignement supérieur pour donner aux archéologues les compétences pour travailler sur les industries extractives.

Les résultats de la première partie du Research Framework serviront à définir des priorités pour les recherches futures. Dans le même temps, ces données aideront à établir des stratégies de conservation et contribueront à sensibiliser l'opinion à l'importance des industries extractives comme une ressource culturelle.

Vorwort

Diese Broschüre enthält den ersten Teil eines Forschungsrahmens für die Archäologie der Extractiven Industrien in England, durchgeführt von der National Association of Mining History Organisation, teilweise gefördert durch Historic England (ehemals English Heritage) und in erster Linie aus den Fachkenntnissen des 'Freiwilligen' Sektors bezogen. Es war das erste Mal, dass eine solch umfassende Bewertung der historischen Bergbauindustrie angestrebt wurde und diese Gelegenheit wurde genutzt um eine eingehende Untersuchung mit veröffentlichten Quellen durchzuführen, bevor der aktuelle Stand der archäologischen Untersuchung aufgenommen wurde. Dadurch verbindet sich aktuelle Kenntnisse auf einer breiten Palette von Fragen, der geologische Hintergrund, die angewandten Technologien, die Infrastruktur der Industrien, einschließlich der Auswirkungen auf die Verkehrsverbindungen und Ansiedlungen. Es untersucht auch historische, Dokumentenforschung und unser Wissen über die Industrien basierend auf archäologische Untersuchungen, nicht nur für die Extraktion (Bergbau und Steinbau) der Mineralien, sondern auch ihre Herstellung und Verarbeitung vor Ort oder nahe der Entnahmestelle.

Die Ressourcenbewertungen können gemeinsam oder individuell gelesen werden. Sie sind chronologisch geordnet, von den prähistorischen Zeiten bis zum Ende der römischen Besetzung. Deshalb wird jede Mineralkategorie getrennt behandelt - Schüttmineralien, Kohle, Eisen, Ton, Blei, einschließlich Silber und Zink, Zinn, Kupfer, Gold, Gangmineralien und Pigmente, die Nebenmetalle, und dann Salz und andere Evaporiten. Diese werden dann zweimal fachlich geprüft - die unterirdische Archäologie und dann folgt die Prüfung der Anwendung der archäologischen Wissenschaft zur Erforschung der mineralgewinnenden Industrie.

Unter Verwendung der historischen Umgebung Aufzeichnungen (Historic Environment Records HERs) als Ausgangspunkt bot ein Gesamtbild für die archäologische Untersuchung, die ein Ungleichgewicht im ganzen Land zeigte. Einige Aspekte der extraktiven Archäologie hatten ein höheres Profil. Die nachfolgenden Prüfungen ergaben auch deutliche Ungleichgewichte in dem veröffentlichten historischen Material, das durch Kohle und den Nichteisenmetallen dominiert wird. Archäologische Untersuchungen, viele davon unveröffentlicht, haben auch ein Ungleichgewicht zugunsten der Nichteisenmetalle gezeigt, jedoch mit wenig effektiver Untersuchungen der Kohle oder der Großmineral (Bergbau) Industrie. Untersuchungen der Eisenproduktion zeigte das es sich fast ausschließlich auf die Verarbeitung (Verhüttung) konzentriert anstatt der Extraktion (Bergbau) von seinen Erzen.

Das Ergebnis der Prüfungen hat Lücken in unserem Wissen über alle Aspekte der Vergangenheit des Bergbaus enthüllt. Unter Verwendung der verfügbaren Ressourcen und der archäologischen historischen Beweise wurde Potenzial für neue oder weitere Untersuchungen identifiziert und diese werden in einem breiten Spektrum von Themen, in einer Reihe von Forschungen in der Forschungsagenda vorgestellt. Dazu gehören nicht nur diejenigen, spezifisch für bestimmte Mineralstoffe, sondern auch andere mit übergreifenden Prioritäten, einschließlich der Methodik und der Notwendigkeit einer verstärkten Ausbildung und Kapazitätsaufbau in der Hochschulbildung, um den Archäologen die Kenntnisse zu geben die Rohstoffindustrie zu untersuchen.

Die Ergebnisse dieses ersten Teils des Forschungsrahmens wird dazu verwendet die Prioritäten für die weiteren Untersuchungen zu entwickeln. Es bietet auch Informationen, die bei der Bildung von zukünftigen Erhaltungs- und Forschungsstrategien behilflich sein werden und dazu beitragen das allgemeine Bewusstsein für die Bedeutung der mineralgewinnenden Industrie als kulturelle Resource zu erhöhen.

I Introduction

I.1 Summary description

Until now, no comprehensive overview has been carried out for the archaeology of the extractive industries; mining, quarrying and the associated infrastructure.

This project has, over a period of five years, assessed and analysed current knowledge, to determine the extent, depth and relevance of research already undertaken for a wide range of mining and quarrying activities, reflecting on their geological and technological context. The results are published here as a Resource Assessment and Research Agenda for England, with a view to formulating strategies for future archaeological research. This publication will also provide information that will assist in forming future conservation and outreach strategies, and help to raise general awareness of the significance of the extractive industries as part of England's cultural resource.

I.2 Background to the project

The need for informed strategies for archaeology in Britain had been recognised by the early 1980s and a number of interest groups had already started to address the problem. The Prehistoric Society published a document on *national priorities for prehistoric archaeology* in 1981, updated under slightly different titles in 1984 and 1988, and others followed – *Priorities for the preservation and excavation of Romano-British sites* (SPRS 1985), *Archaeology and the Middle Ages* (Society for Medieval Archaeology, 1987), and *Resource priorities for post-medieval archaeology* (Society for Post-Medieval Archaeology, 1988). With the implementation of planning guidelines in the early 1990s, PPG 15 and PPG 16 (*Department of the Environment Planning Policy Guidance Notes*, covering Archaeology and the Historic Environment), and now designated as *Planning Policy Statements*,¹ there were significant changes in the way that archaeological work was undertaken. Much archaeological investigation is now led, and funded, by developers and that has accentuated the need for coherent objectives. English Heritage published

a number of documents, *Exploring our Past* (1991), *Frameworks for our Past* (1996), which highlighted the need for detailed research frameworks to effectively target future research and this is reinforced in their recent *Strategy for Developing Research Resources* (2013). A number of regional groups had already considered the overall archaeological research priorities in their areas and these were developed as the regional research frameworks sponsored by English Heritage to provide it with an informed strategy for future research.

English Heritage also sponsored research framework projects by specialist interest groups, of which the Association for Industrial Archaeology's *Understanding the Workplace* (Gwyn & Palmer 2005) and *Metals and metalworking: a research framework for archaeometallurgy* (Bayley et al. 2008), compiled by the Historical Metallurgy Society, were particularly relevant to this project. The former covered the period post 1750 and specifically excluded the extractive industries, referring the reader to an early study, *The Archaeology of Industrialisation* (Barker & Cranstone 2004), which include a small group of papers on mining by Willies, Blackburn, and Mighall et al. Those papers, whilst extremely useful in their own right, do not address the problems of developing a research agenda for the future of mining and quarrying archaeology. The work of the Historical Metallurgy Society touches on mining, albeit only the extraction of metals, from prehistory through to the modern period but its primary focus is on metal working and it could not be expected to address future research for the historic extractive industry as a whole. In 1992, at the request of the short-lived Institute of Mining History and Archaeology, David Cranstone prepared a short article on the *Priorities for Research and Preservation* (1992c) and shortly afterwards *The Archaeology of Mining and Metallurgy in South-West Britain*, (Newman 1996a) did go some way towards addressing aspects of current research. The English Heritage statement on *Mineral Extraction and the Historic Environment* (2008a) has also highlighted the historic significance of mining and quarrying sites and landscapes, and their importance for the conservation

of the built environment.

Following discussion with English Heritage (Jon Humble, Senior Policy Adviser – Minerals) in 2006, the National Association of Mining History Organisations (NAMHO) considered how it might provide a comprehensive Research Framework for the Archaeology of the Extractive Industries, utilising the expertise within its constituent organisations and other bodies with interests in the extractive industries. An initial appraisal of the project was carried out, and a Steering Group established, leading to an outline proposal. Agreement was then reached with English Heritage (Historic Environment Commissions) for funding for the preparation of a Project Design, which was completed in July 2009.

A Project Officer was appointed in October 2009 and the work of the project commenced in November of that year. Delays were experienced in acquiring and processing the data from the Historic Environment Records (HERs) and prolonged consultation was required to identify individuals with expertise in some areas outside the mainstream areas of interest within the mining history community. Specialist study groups were then established and tasked with providing draft Resource Assessments. Progress was evaluated at regular intervals and the time scale adjusted as necessary as the amount of data in those assessments increased dramatically.

Following the HER trawl (below), consultation among researchers commenced with a series of seminars held at Gunnislake (Cornwall), Snibston (Leicestershire), Caphouse (Yorkshire), St Austell (Cornwall), Carnforth (Lancashire), Wirksworth (Derbyshire). The aim of these events was to draw out information from a broad spectrum of mine and quarry researchers, historians and archaeologists, and to provide as comprehensive a body of information as possible on which to base the assessments.

A methodology (below) was developed which ensured that all aspects of the extractive industries, including the understudied minor minerals, were covered; current knowledge was assessed, and the aims and objectives for future research formulated. What is presented here is the result of over five years of detailed enquiry and can be seen as a significant exercise in self-education for the mining history community.

1.3 The case for this specialist research framework

No study providing a comprehensive overview of the archaeology of mining and quarrying, assessing the state of knowledge and the priorities for future research, has been carried out prior to this. If the archaeological

community and those bodies funding future research are unaware of the current state of our knowledge, opportunities to advance our understanding are likely to be missed.

Mining and quarrying in Britain dates back over 6000 years into the Mesolithic period, when selected materials, stone, flints, clay and pigments, were dug out of the ground for use as tools, as cultural symbols and, from at least the early Neolithic period onwards in England, for the production of ceramics. The impact of the products from mining and quarrying have defined phases in human development from the Neolithic and Bronze Ages to the Industrial Revolution of the late 18th and early 19th century, and the urban lifestyle of today. The economic and cultural importance of the extractive industries in England was immense, with the early coal and metal mining industries making significant contributions to the process of industrialisation, which culminated in the rapid changes of the late 18th century. At its peak, in the first years of the 20th century, the coal industry alone employed up to ten percent of the working population. Physical evidence for mining and quarrying is to be found in every part of the country, from the lowlands of the Southeast to the uplands of the North and West, in city centres and amongst their suburban sprawl, as well as on remote hillsides and cliff tops. Mining and quarrying continue to be active industries, sometimes destroying the evidence of earlier working and at other times exposing it for closer investigation. There is an ongoing need to recognise the value of the evidence and be aware of its potential.

The archaeological evidence currently available for mining and quarrying is, however, quite variable with some sectors having been examined in great detail whilst for others information is sparse or non-existent. For some periods and geographic areas there might be documentary evidence but a full examination of the field evidence has not been carried out: whereas, for others, physical features have been identified and entered in the Historic Environment Record (HER) but not subject to a structured programme of research. An example of the latter might be post-medieval ironstone mining on the Jurassic Ridge in the Midland counties of England. This industry is well represented in the HER, and was important historically as a major source of supply to the iron and steel industries during periods of conflict in the 20th century, but has not been subject to detailed archaeological or historical investigation at a local level.

This research framework project has assessed current knowledge of mining and quarrying, its cultural impact and the chronology of landscape features. The project considers the depth of knowledge for the industries both regionally and chronologically, through

examining their unique features, and reassesses current views against the range of data collected. It also provides geological and historical narratives against which the archaeological resources can be considered in context. The outcomes, presented here as Resource Assessments and Research Agenda, will now be used in the preparation of a Research Strategy, establishing research objectives and possible priorities.

The publication is intended to address objectives originally set out in English Heritage's Strategic Framework for Historic Environment Activities and Programmes (SHAPE), sub-programme 11172.110, by providing a research framework which might be used to support future projects. It also fulfils the priority highlighted in *Mineral Extraction and the Historic Environment*, which stated that: 'A proper understanding of the historic resource is a key step, and there is a need for a national research framework for the extractive industries, including recommendations for promoting their conservation, public appreciation and considerable potential, as an educational resource' (English Heritage 2008, 7).

It is therefore available to support the work of Historic England, which took on the Heritage Protection role (originally carried out by English Heritage) in April 2015, in developing the new Action Plan for 2015-2018². As such, this Research Framework will be an integral part of the resources used to inform an understanding of the historic environment at national and local levels; being a key element within Historic England's Strategy for developing Research Resources³ and a guide to the future direction for research in the voluntary and academic sectors.

Certain sections within this Framework will have importance in informing policy aimed at protection of elements unique to the heritage of the extractive industries. This is particularly so with the consideration of underground mining and quarrying remains, where access is reliant on specialist skills held predominately within the voluntary sector. The work done by Barnatt and others (Barnatt *forthcoming*) has already highlighted the potential in this area, which is amongst Historic England's priorities for Protecting Industrial Sites⁴.

Overall the strengths and shortcomings identified here will be pivotal to the direction for further action, and will have a real impact on the future for the historic environment in relation to the extractive industries. This Research Framework should, however, not be seen as a static document and regular revisions are envisaged to highlight the progress towards a greater understanding of the history and archaeology of the industries.

1.4 The structure of the research framework

The Research Framework for the Archaeology of the Extractive Industries in England as a whole is intended to address the lack of a comprehensive overview of the archaeology of mining and quarrying. In doing so it provides the knowledge which might be used to inform the course of future research. This has been structured in three parts:

1. Resource Assessment: providing an understanding of the current state of knowledge and the available resources, both archaeological and historical.

2. Research Agenda: to identify the strengths and weaknesses in that knowledge, the unique elements and the potential for future research.

3. Research Strategy: to establish research objectives and possible priorities.

The first two parts are the subject of this publication. Its contents will be used as the basis for the third part, developing a Strategy which will consider providing a prioritised list of research objectives for the archaeology of mining and quarrying.

The overall aims and objectives of this project are therefore to:

- review and assess the archaeological resources for mining and quarrying
- identify similarities and common themes across the industries
- identify areas of weakness, assess the strengths which might inform approaches to address those weaknesses, and suggest potential directions for future research
- link into national, regional and other related thematic strategies
- link into those cross-cutting themes which have a bearing on the archaeology of the extractive industries
- involve the mining history and archaeological communities at all stages; to inform them on the extent and quality of current knowledge
- identify gaps in current knowledge and research objectives, with a view to filling those gaps and expanding our knowledge of mining and quarrying archaeology
- identify shortages in skill levels relevant to the archaeology of the extractive industries; ensuring that they will be equal to the challenges presented in taking forward the required archaeological research
- assist in informing future conservation and outreach strategies, and helping to raise general awareness of the significance of the extractive industries as part of our heritage.

1.5 Defining the extractive industries

For the purposes of this project an extractive industry, mining or quarrying, is defined as *the extraction of materials from the ground, where the material extracted was the primary objective (actual or perceived)*. It also includes the processing of the material extracted where that is carried out on or near the site of extraction.

The project has assessed the available evidence for mining and quarrying, the extraction and processing of materials, and their wider impact on the landscape, including cultural and social implications. A wide range of materials have been worked in the mines and quarries of England and these can be broadly categorised as follows:

Energy minerals

- coal
- oil shale

Metals

- iron – Mesozoic ironstones, coal measure ironstones, and other iron ores
- non-ferrous metals – lead, copper, tin, etc.
- associated gangue minerals – barytes, fluorspar, etc.
- pigments – ochre etc., and including graphite and carbon black
- minor metals/minerals – antimony, gold, arsenic, manganese, cobalt, etc.

Bulk minerals

- stone – building and roofing materials, aggregates, industrial use, e.g. lime
- sand and gravel – aggregates and industrial use, e.g. glass, moulding sands

Other industrial minerals

- evaporites – gypsum, salt, potash, celestite, etc.
- clays – ‘common’ clay, ball clay, china clay, fireclay, potter’s clays, etc.

The extraction of oil, gas, water by means of wells and boreholes, and the digging of peat are excluded from the project; reference may, however, be made to those extractive industries where they are relevant to mining and quarrying, both surface and underground, or the associated processing of material. For example, the supply of peat as fuel for on-site smelting of lead and tin. Also excluded is mining activity where it was carried out for the primary purpose of creating a tunnel or underground space, for example during military operations or as a transport facility, unless that was linked to or preceded by mining or quarrying for minerals as defined above. The project is confined to land based extraction and therefore excludes off-shore

and marine based extraction.

Although the terms ‘mining’ and ‘quarrying’ conventionally refer respectively to underground and surface-based operations, legally, industrially, regionally, and in the vernacular, usage varies and so the terms cannot be universally applied. For example opencast coal workings are often referred to as mines, yet the underground extraction of Bath stone is also known as mining

Attention has also been given to cross-cutting themes, for example, the cultural impact of the industries including customary practices, settlement and migration. The underground nature of the industries and the potential for significant elements in their archaeology surviving underground, have also been addressed by the project: contributing to English Heritage’s SHAPE Research Programme A2, sub-Programme 11112.210, *New Frontiers: Understanding Subterranean Places*, and are being considered for protection by Historic England through the designation process.⁴

1.6 Methodology

The process of compiling the resource assessment began in 2010, and commenced with a search of England’s Historic Environment Records (HERS). These data bases are compiled and curated by county and unitary councils, national parks and several other organisations, such as the MoD and the National Trust. A report on general conclusions drawn from this search, as of August 2010, was published on the NAMHO website, from which the following summary is derived.

1.6.1 The historic environment records

Seventy-four HERs were approached to supply data for the framework, of which 62 responded to a search request sent to them between November 2009 and February 2010. Most provided the requested data, though in some cases, it was necessary for an online search to be undertaken by the project officer.

Digital searches of HERs will rarely succeed in retrieving information on all the material held. While some HERs have been able to transcribe written material in full within the digital record, or include a précis, for others, external material is simply mentioned under further sources. Some HERs also have backlogs waiting to be input, the scale of which depends on their available resources and it is difficult to estimate what effect this has on the results of these searches.

The majority of records covering the extractive industries within HERs, with some exceptions, come from secondary data sources, e.g. historic OS maps and aerial photo transcriptions. As a result, the data they

possess for many mine and quarry sites is limited to location and extent, as established from these sources. However, the HERs that have fully utilised historical mapping and AP transcriptions in this way, do represent a good starting point for general studies of quarries and mines, having collated much of the necessary spatial data.

Additional historical and archaeological information for some individual sites is available from a number of sources, and these have often been incorporated into HER records. But this has not been universal and within all HERs there is potential for further enhancement from existing published sources.

Some aspects of extractive archaeology have been favoured with more attention from archaeologists than others and, as a result, have a higher profile within HERs. These include, in particular, prehistoric mining such as flint and copper, early iron smelting, and Roman salt extraction. The evidence of medieval tin streaming, tin mining, coal mining, iron extraction, lead mining (in certain regions), and all forms of smelting, also have well-developed networks of researchers whose published material has found its way into HERs. This is less so for other industries, especially quarried minerals, the field evidence for which has attracted much less interest among archaeologists.

Underground archaeology also has very little presence within HERs. Although often considered to be sensitive information, sometimes not made available to the public, there is also an acute shortage of researchers with the specialist skills needed to supply data.

On the whole, HERs tend to refer to professionally compiled sources of archaeological data, either gleaned from publications or through field investigation, yet in the field of mining archaeology, the independent circle of researchers is more prevalent and often more knowledgeable, especially at local level. Some HERs have benefited from the contribution of these researchers, either through IRIS or less formal contact.

For the purposes of the Framework, the data gleaned from these HER searches was collated into thematic and county bibliographies, then published on the Internet. Much additional material was added after scrutiny by independent researchers, with either a regional interest, or specialist knowledge of extractive industries. It has also been one of the project officer's tasks to seek out lesser known publications and unpublished material to pass on to the subject specialist appointed to write the assessments.

1.6.2 The assessments

The 14 assessments in this volume have been drafted by individuals who have acted as the main subject specialist for each topic. Their brief consisted only of a set of

headings, covering topics considered essential to the requirements of a research assessment. Nevertheless, each author has approached the task in the way they felt was appropriate for their topic, so style, content, and level of detail within the individual assessments, varies. Repetition was a problem at editing stage as, inevitably, several authors wished to make similar points. Where appropriate, repetition has been removed or replaced by cross-referencing, though in some cases it was felt necessary to allow issues to be covered more than once, as authors needed material examples to make their point. Readers will note therefore, that some geological, technical and historical matters are repeated, but as the assessments are each designed to be read separately, this was considered permissible.

Drafts were published on the world-wide-web for a period of consultation, and regularly updated in the light of additions, improvements, and corrections contributed by colleagues. Collating and editing this material into the draft documents and this final publication was undertaken by the project officer (Phil Newman) who assumes full responsibility for any errors that may have slipped in during this lengthy process.

Notes and Internet references

1. For example - PPS5: Planning for the Historic Environment: Historic Environment Planning Practice Guide, (English Heritage 2010), www.english-heritage.org.uk/publications/pps-practice-guide/pps5practiceguide.pdf [accessed 26 March 2014]
2. <https://content.historicengland.org.uk/images-books/publications/he-action-plan-2015-18/he-action-plan-2015-18>.
3. <https://content.historicengland.org.uk/content/docs/research/he-strategy-developing-research-resources>.
4. <http://historicengland.org.uk/advice/heritage-at-risk/industrial-heritage/protecting-industrial-sites/>

1.7 Geology and structure

Tim Colman and Joseph Mankelov

The geology of England is extremely varied and complex, but it can be divided into a relatively small number of chronostratigraphic units (Fig 1.1) and a generalised tectonic framework (Fig 1.2). The following summary is based on a large volume of published information, but notable sources include Anderton *et al* (1979), Craig (1991), Duff and Smith (1992), Hancock (1983), Harris *et al* (1979) and Windley (1995). The Atlas of Palaeogeography and Lithofacies (Cope *et al* 1992) is an excellent overview of the geological development of Britain. More detailed information is given in the series of handbooks on the regional geology of Great Britain and Northern Ireland published by HMSO for the British Geological Survey. Information on the bedrock and superficial geology of Britain (BGS, 2012) and the distribution of mineral resources (BGS, 2008) is also available on-line.

Precambrian

The oldest rocks in England occur in the late Precambrian NeoProterozoic Midlands Microcraton of Central England (Fig 1.2). This is a fragment of the former microcontinent of Avalonia that formed around 730Ma as an island arc near the margin of Gondwana. It is now almost completely concealed by younger rocks but there are small outcrops of late Precambrian volcano-sedimentary sequences in the Welsh borders around Church Stretton (The Longmynd and Caer Caradoc) and the English Midlands (Nuneaton and Charnwood Forest). Its boundaries are largely conjectural (Pharaoh *et al* 1987). It has been intersected at depth by a few boreholes. There is little mineralisation in the exposed areas. The Hughton and Wrentham baryte veins, with minor copper, occur in the Longmynd sediments and may be part of the Shropshire lead-zinc-baryte orefield found in adjacent younger rocks to the west.

Lower Palaeozoic

Lower Palaeozoic formations in England are mainly found in the Lake District where they consist of basic to acid volcanics and volcanoclastic sediments with thick basal greywacke turbidites and coeval shelf sediments which extend as far east as Teesdale in County Durham. The two continental blocks of the North Atlantic and Eurasian cratons were on opposite sides of the Iapetus Ocean, which was gradually closing in a complex way with subduction on both sides.

Volcanism also occurred during the Ordovician in the concealed Lower Palaeozoic rocks to the east of the Midlands Microcraton) as southward subduction of

the Iapetus Ocean floor continued. Thin Cambrian to Silurian sediments were deposited on the continental shelf of Midlands Microcraton in Shropshire and Warwickshire and Ordovician mudstones have also been found at depth in Derbyshire in the Eyam borehole.

Caledonian orogeny

Closure of the Iapetus Ocean was complete by late Silurian to early Devonian times along the line of the Iapetus suture in northern England (Fig 1.2). The rocks to the south side of the Iapetus Suture, were less highly tectonised. The main effect was the development of a pervasive slaty cleavage. Exposed granites occur in the Lake District and a number of concealed granites have been indicated by gravity studies in the last thirty years. Some, such as those underlying Weardale and Wensleydale in northern England, have been proved by drilling. Others, such as those around the Wash in eastern England, remain largely conjectural. Lower Palaeozoic rocks overlying the Midlands Microcraton were almost undeformed.

The end-Caledonian orogeny is associated with a period of intense metalliferous mineralisation. Granite-associated Cu, Au, Mo and W mineralisation occurs in the Lake District. Sediment-hosted Pb-Zn±Cu±Ba vein mineralisation occurs in the Lake District and Shropshire. Turbidite-hosted gold mineralisation occurs in the Lake District.

Upper Palaeozoic

The Upper Palaeozoic Devonian to Permian successions were mainly deposited on a stable platform and consist predominantly of clastic and carbonate sediments. Local extensional basins, such as those of Craven and Solway-Northumberland, developed in the early Carboniferous. General continued subsidence led to the deposition of thick deltaic mudstones and sandstones with associated workable coals in the late Carboniferous (Westphalian). These were followed in Permian times by red-beds containing thick evaporites.

In Southwest England block and basin limestones and shales, spilitic basic volcanics and turbidite deposits were laid down in an extensional basin developed at the western end of the Rheno-Hercynian zone. Shallow-water clastic sediments were deposited in north Devon, which lay on the northern margin of the basin.

Contemporaneous mineralisation includes salt, gypsum and potash deposits of Upper Permian age in northern England. Thick anhydrite beds also occur at depth in the basal Carboniferous (Tournaisian) sediments of the Solway Basin and the Widmerpool Gulf of Leicestershire. Minor synsedimentary Zn-Pb mineralisation occurs in the early Carboniferous of the Craven Basin and around the Devonian/Carboniferous

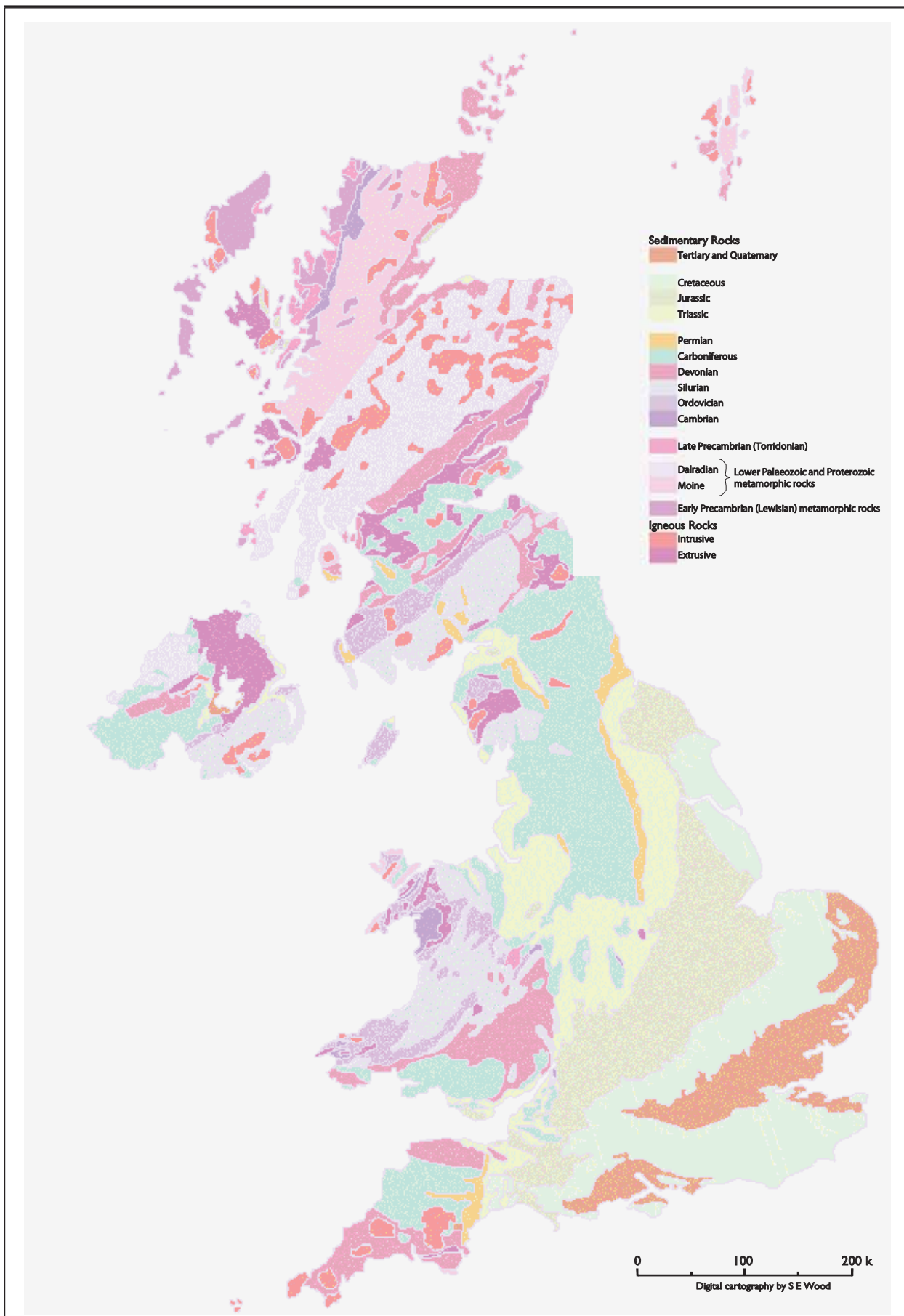


Figure 1.1 Map of the British Isles showing chronostratigraphic units.

boundary in south-west England. The Craven Basin mineralisation shows some similarities to the important early Carboniferous Zn-Pb deposits in the Republic of Ireland, such as those at Navan. Disseminated and vein-style gold mineralisation has recently been discovered close to the junction of Permian red-beds and associated alkaline basalt lavas with older rocks in south-west England and southern Scotland.

Variscan orogeny

The Variscan orogeny from late Devonian to early Permian times was caused by a complex series of movements and collisions between Europe, Africa and North America. The main areas affected in Britain were the Variscides in southern England and South Wales (Fig 1.2). The orogeny caused deformation and tectonism and culminated in the emplacement of the high-heat-flow, Cornubian batholith which extends for 230 km from the Isles of Scilly to Dartmoor. The batholith is exposed as a series of large bosses and minor cupolas with which the major Sn-Cu-W vein-style mineralisation of south-west England is associated. The mineralising fluids also altered large volumes of granite which are now exploited for their kaolin or china clay content. More gentle folding and faulting

occurs to the north of the Variscan front (Fig 1.2) where Dinantian carbonates host major vein and replacement Pb-F-Ba mineralisation in the limestones of the Northern and Southern Pennine orefields and the Mendip Hills. Replacement hematite deposits formed near the contact of Dinantian carbonates and overlying Triassic sandstones in the western Lake District.

Post Palaeozoic to present

Post-Palaeozoic formations consist mainly of shallow-water, marine clastics and limestones devoid of significant mineralisation. The principal exceptions are Permo-Triassic basins containing red-beds with thick evaporites and extensive Jurassic sedimentary ironstones in the English Midlands. Red-bed Cu mineralization occurs in the Triassic rocks of the Cheshire Basin. Economically significant ball clay deposits of Tertiary age occur associated with sands and lignite in basins at Bovey Tracey and Petrockstow in Devon and Wareham in Dorset. The whole country, apart from the extreme south-west, was affected by Quaternary glaciation. This caused deep erosion in upland areas and has left widespread superficial deposits of sands and gravels which are exploited in most areas.

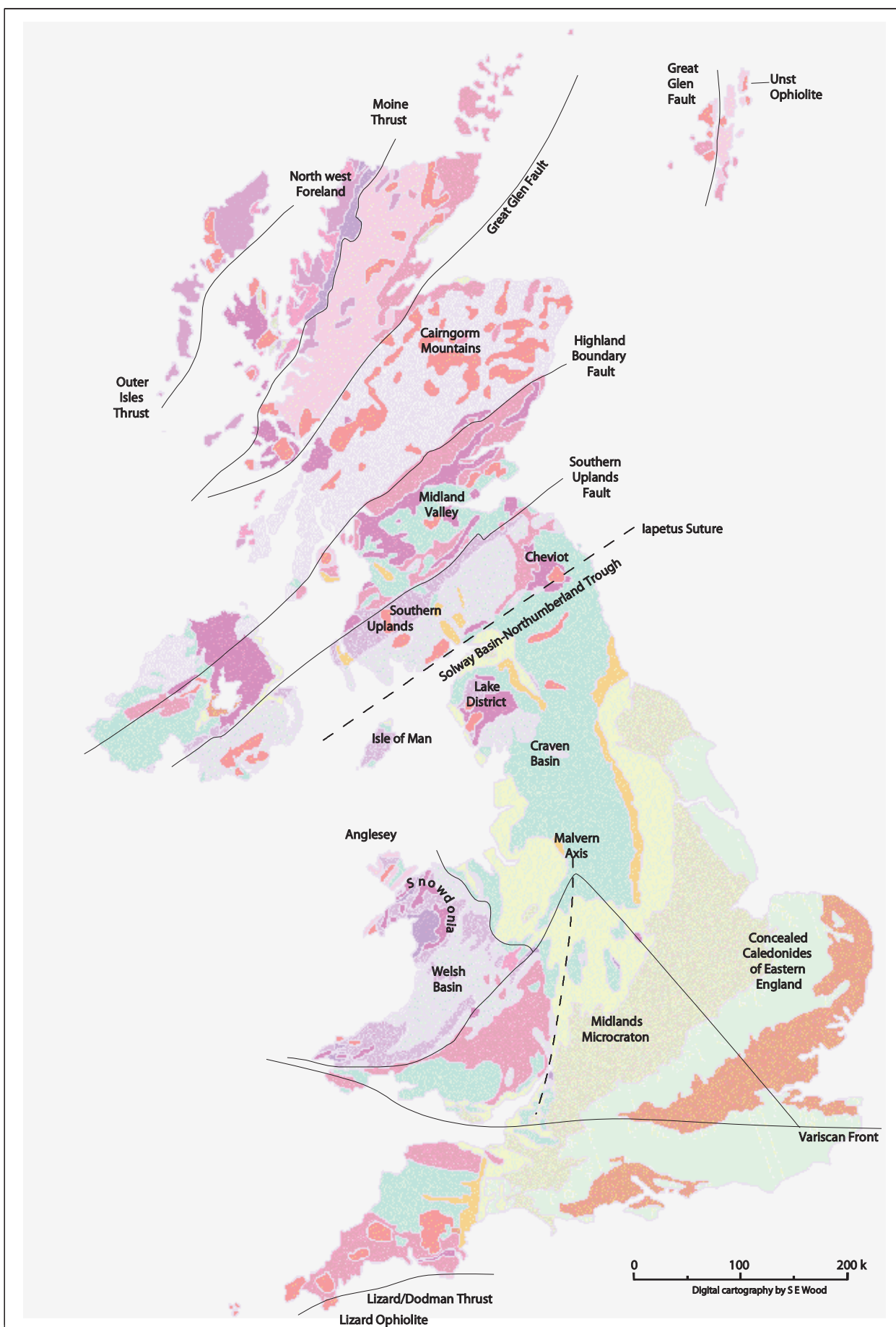


Figure 1.2 Map of the British Isles showing a generalised tectonic framework.

2 The Prehistoric and Roman Periods

Simon Timberlake

Contributions from John Barnatt, Lee Bray, David Cranstone, John Pickin and Phil Newman

2.1 Non-ferrous Metals

2.1.1 Prehistory

Context

Since the late 1980s, there has been an abundance of archaeological research based around field discoveries and small to larger scale excavations at prehistoric copper mines in Britain. Twelve sites have been dated to the Early Bronze Age, and over 30 publications have appeared (including Dutton & Fasham 1994; Jenkins 1995; Timberlake 1990a & b; 2002a & b; 2003; 2009a & b; Timberlake & Prag 2005), as well as some unpublished material, such as Lewis (1990 & 1996). All but two of the sites investigated so far (Alderley Edge and Ecton) are in Wales (including eight excavated and dated sites: Copa Hill, Cwmystwyth; Nantyreira; Nantyrarian; Tyn y Fron; Twll y Mwyn; Erglodd; Llancynfelin; and Ogof Wyddon), particularly within the mid-Wales orefield. Most significant amongst these is Copa Hill (Timberlake 2003), but two other important mines on the North Wales coast are Great Orme, Llandudno (Lewis 1996 unpub) and Parys Mountain on Anglesey (Timberlake 1990a; Jenkins 1995)¹.

Mixtures of oxidised sulphidic ores including chalcopyrite and malachite – sometimes intimately mixed with galena within the surface oxidised, supergene zones of these vein deposits – were being worked to depths of about 10m within opencasts and up to 30m underground (within the limestone of the Great Orme). Evidence of working methods includes firesetting and/or the use of bone or antler picks and an assemblage of hafted and hand-held stone tools. These consist of a preferential selection of beach cobbles, brought sometimes up to 25km from the coast (at Copa Hill) and recycled on site.

It is likely that the exploitation of the British Isles copper resources began in Southwest Ireland at the Beaker-period mine of Ross Island, Killarney (O'Brien 2005) in c.2400 BC. Following the depletion and flooding of these workings in c.1800 BC, the search for new sources of copper moved to the red bed cupriferous

deposits of the Old Red Sandstone at Mount Gabriel and other sites in Cork, where prospecting and small-scale mining is evident (Jackson 1968; O'Brien 1994). Then to the Isle of Man and the deposits of Bradda Head and Langness, where stone mining hammers have been found (see Doonan & Hunt 1999). On the west coast of Britain, the copper and lead vein deposits within the Lower Palaeozoic rocks of the mid-Wales uplands, along with the gossans of the massive sulphide deposit on Parys Mountain and the Carboniferous Limestone (a Mississippi Valley type copper deposit), began to be prospected and worked regionally from c.1900-1800 BC. However, some of the mid-Wales sites have provided earlier dates including Erglodd, c.2200 BC; Tyn y Fron, 2100 BC, and the earliest exploitation of the lode outcrop on Copa Hill of between c.2100 – 2000BC. These dates deserve further examination in the context of earliest mining studies in Britain, but what is clear is that almost all of these mines had been abandoned and the widespread phase of prospecting was over by 1600-1500 BC. This phenomenon can in part be explained by the exhaustion of easily-won oxidised ores and the increasing depth of workings creating rising water (drainage) problems. The latter may be linked to climate deterioration and increased precipitation, particularly within the uplands, where many of these sites were located. This inundation has been demonstrated archaeologically at Copa Hill (Timberlake 2003). However, this is probably only part of the answer at a time when new sources of European copper, such as from the Alps, were coming on stream, and political and economic allegiances were playing important roles in this change. Future research will need to address these issues.

Just as interesting, though perhaps less surprising, given the naturally well-drained limestone (perhaps with karstic openings) of this headland, is the continuation of mining of unknown scale at the Great Orme into the Middle Bronze Age (c.1500-1400 BC), and even into the Late Bronze Age and Iron Age. The latter is based on the limited number of later radiocarbon dates, some of which were obtained from the deeper

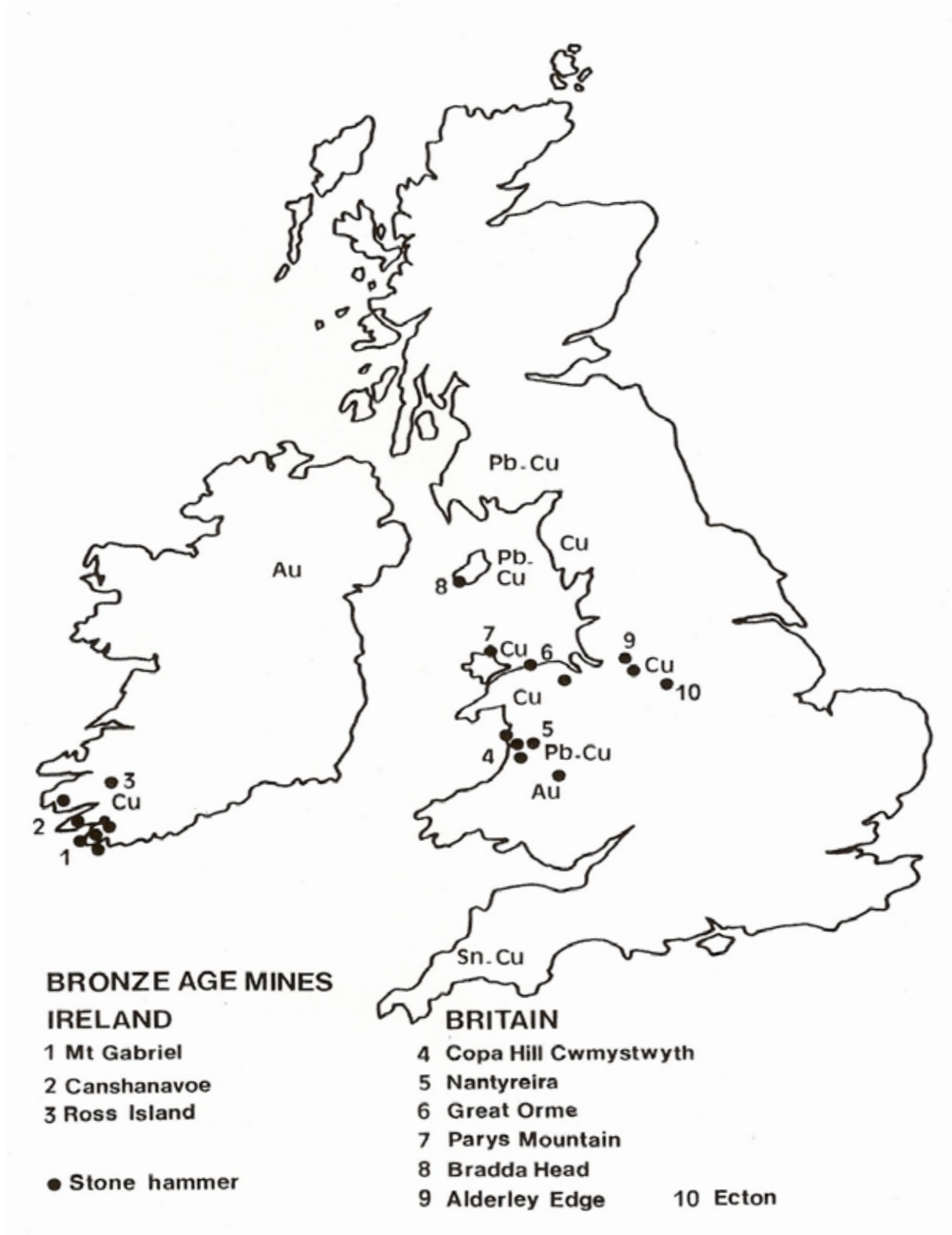


Figure 2.1 Map of Great Britain showing known distribution of Bronze Age mines. Brenda Craddock

parts of the mine. This Middle Bronze Age extraction may well equate with the production of the Acton Park bronze metalwork in North Wales (Timberlake 2009a; Tylecote 1986). Northover (*in Savory 1980*) also suggests that the impurity-free Type C copper of the Early Bronze Age may originate from the Great Orme, with the low nickel and arsenic metal types B1, B3 and

B4 originating from Mid- and North Wales. Rohl & Needham's (1998) work on the lead-isotope analysis of British ore deposits suggest a correlation between the IMP-LI 6 type metal and some of the Mid-Wales ores (such as from Copa Hill) on the England & Wales Lead Isotope Outline (EWLIO) plot.

Most significant on the list of future research

questions to be addressed, is the absence of evidence for smelting sites associated with these Early to Middle Bronze Age mines. Archaeological fieldwork has failed to find traces of this within the vicinity of the mines, whilst palaeo-environmental investigations of peat basins nearby these sites have identified (copper and lead) palaeo-pollution peaks within the peat associated with mining activity. However, it has not been possible to distinguish whether or not these relate to smelting flume or to wind-blown dust emanating from the prehistoric mines (Timberlake 2003; Mighall & Chambers 1993; Mighall et al. 2000). Apart from roasting pits, and a number of possible but enigmatic smelting features identified by O'Brien (2005) at the Beaker mining camp on Ross Island, Killarney, the only site from the UK which could be copper smelting of Bronze Age, is Pen Trwyn on the northern cliffs of the Great Orme headland. Although largely destroyed, the hearth and Early Bronze Age pit contained a few grams of crushed slag and copper prills (Chapman 1997; Jones 1999).

Given the importance of the Welsh finds, the more recent and current work in investigating the origins of copper mining in England take on added importance; in particular with regards to what other, as yet undiscovered, sites remain and how much (or how little) of the copper from these sites was entering the body of metalwork of the British Bronze Age. The subject of production figures of copper from these mines, and the amount of re-cycling and import of metal, is addressed in *Copper Mining and Metal Production at the beginning of the British Bronze Age* (Timberlake 2009a).

Apart from salt-working and iron production sites, and of course the incidental but significant investigation of gravel, chalk and stone quarrying as part of what are usually seen as much broader archaeological landscape projects, the investigation of Bronze Age copper mining over the last 20 years has probably been the main archaeological excavation project(s) in the UK to explore mineral extraction in the prehistoric to Roman period.

2.2 Mineral Pigments

2.2.1 Prehistoric

Alderley Edge

The possibility of prehistoric extraction of mineral pigments (chiefly malachite and azurite, but also manganese wad, iron oxide and pyromorphite) from the Trias Bunter and Keuper sandstones of Alderley Edge in Cheshire, has been hypothesised by Timberlake (2005a; 2009a). It may have occurred during the Mesolithic to Early Bronze Age, though so far no clear archaeological

evidence has been found. The suggested locations for this activity are the soft Bunter (Upper Mottled Sandstone) at Pillar Mine and the interbedded mudstone horizons (containing azurite nodules) at the base of the Engine Vein Conglomerate at Devil's Grave and Engine Vein. The circumstantial evidence for this includes sites of Mesolithic occupation indicated by flint scatters on the Edge. These were first described by Roeder (1901) and recently confirmed in a survey (Timberlake & Prag 2005). They occur (perhaps coincidentally) alongside mineral outcrops. None of these sites, including the significant survivor at Castle Rock (Cowell 2005), have been excavated, yet the investigation of this possible mineral and resource connection with these Mesolithic seasonal camp sites is just one of the research questions which should be addressed.

Forest of Dean

There may be early evidence for iron ochre pigment extraction in the Forest of Dean, Gloucestershire. This is in the form of rare small, hand-held, cobble implements used as crushing stones, presumably for haematite, some of which have been found within old ironstone mines with medieval (and probably pre-medieval origins) such as the Clearwell Caves (*pers comm* Ian Standing). More recently, a small selection of hammerstones have been recovered from the surface of old scowles within a quarry at Drybrook, on the east side of the Severn. Though fashioned from the same type of rock, at least one of these hammers shows distinct evidence of grooving for hafting, whilst another appears to be a small crushing stone. Small cup-marked hollows in bed rock nearby (similar ones have been recorded from other sites in the Forest) have also been interpreted as anvils/mortars for crushing haematite (Strassburger 2000 *unpub*). No date has been ascribed to these workings, but it is has been suggested by Strassburger that they are Bronze Age.

Exmoor

At Roman Lode near Simonsbath on Exmoor, evidence of Early Bronze Age activity has been excavated in the form of a large hearth and a deposit containing anthropogenically smashed quartz. It is associated with the surface outcrop of a haematite lode exploited in historical times for iron (Juleff & Bray 2007). Though the excavators considered that this might have been a prospect for copper, another possible explanation could be as an exploration for haematite ochre pigment.

Cumbria

Pickin (1990) mentions the discovery in the 1870s of 'two polished stone celts of the usual sort' found in old haematite workings at Stainton, Barrow-in-Furness,

Cumbria (Kendall 1893; Tweddell 1876). He then questions whether this might refer to a ritual/burial deposit in a natural cavern, or whether this is evidence for associated mining, presumably for pigment. Little can be made of such a find now, yet prehistoric interest in such a resource is what one might expect.

2.2.2 Roman

Alderley Edge

It is possible that the Roman mine of Pot Shaft at Engine Vein (Timberlake & Kidd 2005) was worked for a blue pigment found in the azurite nodules. These were extracted from a mudstone horizon within the Engine Vein Conglomerate, as well as malachite and azurite disseminated within the softer underlying Bunter sandstones. Pot Shaft is described in greater detail within the sections below on Roman copper and lead mining, yet probably the closest comparison with this working appears to be the Roman mine excavated by the Bochum Mining Museum at Wallerfangen-Saar in Germany (Korlin 2010; Strassburger *pers comm*). This mine was worked for azurite pigment (Egyptian Blue) sometime during 2nd-4th centuries AD. The azurite here was extracted from a fairly similar geological horizon, using much the same type of shaft and level construction.

2.3 Copper

2.3.1 Bronze Age

Southwest England

Fieldwork carried out over the last 20 years (Sharpe 1997) has revealed nothing in the way of conclusive evidence for prehistoric hard-rock metal mining, or copper extraction, within the important (Cornubian) orefield of Cornwall and Devon. Some circumstantial evidence for the use of stone mining tools can be found in collections, such as those of the Zennor Wayside Museum (Craddock & Craddock 1996), yet the only example of mortar stones plus several unconvincing cobble stone tools came from an undated tin/copper openwork surveyed at Wheal Coates Mine, St. Agnes (Budd & Gale 1994). With any of these finds it has not really been possible to distinguish these tools from those used later for the crushing of tin ore. Penhallurick (1986) describes the find of a Middle Bronze Age palstave within an old work at Godolphin Mine, yet the best evidence he provides of hard-rock mining seems to be a mineral specimen of botryoidal goethite, probably dug from a lode, discovered with Middle Bronze Age pottery at Tredarvah.

Attempts to provenance metal artefacts may have provided some firmer evidence for extraction (Budd et al. 2000). This work analysed the lead isotopes and trace metal composition of a group of five Early Bronze Age copper artefacts; the result, it was claimed, indicates unambiguously a source within an ore body associated with the Cornubian granite batholiths, more specifically, the St. Austell intrusion. Although the number of artefacts analysed was limited, these data could be important if they provide confirmation that copper was exploited in Cornwall at a date close to the very beginning of the Bronze Age. There are certainly traces of copper metallurgy in the form of local copper-alloy metalworking surviving at Middle Bronze Age settlements such as Trethellan Farm, Newquay (Nowakowski 1991); yet there is no evidence, here or anywhere, of primary smelting. Three copper ingots of Late Bronze Age date from St. Michael's Mount (Herring 2000) and Kenidjack (Tylecote 1967) might imply local production. But just as interesting, perhaps, is the evidence for Late Bronze Age to Early Iron Age copper, bronze and lead-silver metallurgy at Gussage All Saints and Hengistbury Head in Dorset (Tylecote 1986). The source of the copper used at the latter site is likely to be somewhere in Southwest England.

Isle of Man

The Isle of Man, an island rich in Beaker and Early Bronze Age remains and one of the principal stopping-off points for the earliest seafarers between Ireland and Britain, is also on the route along which some of the earliest metallurgists travelled. There is evidence (though still undated) for prehistoric prospection around the southern tip of the island, such as on the Langness peninsula, where hammer stones associated with an area of copper mineralisation were found during fieldwalking in 1999 (Doonan & Eley 2000). To the west, similar tools made of basalt beach cobbles



Figure 2.2 Engine Vein, Alderley Edge, Cheshire - showing bisected Bronze Age pit workings on side of open-cut.
© Simon Timberlake



Figure 2.3 Engine vein Alderley Edge, Cheshire. © Simon Timberlake

were recovered from North Bradda Head in 1998 (Doonan & Hunt 1999) and from South Bradda Head in 1987 (Pickin & Worthington 1989). Adjacent to the natural harbour of Port Erin, South Bradda forms a prominent headland, which faces west and looks out across the Irish Sea. The visibly copper-stained cliffs are associated with a rich lode containing chalcopyrite, secondary minerals and quartz, a natural feature described by Lamplugh in 1903 as being ‘amongst the most spectacular displays of quartz veining in Europe’. The presence of the mineral here can still be seen far out to sea, much as it would have been in antiquity as the Neolithic and Bronze Age peoples navigated across from Ireland. The existence of this ‘metal route’ seems all the clearer when we examine the Copper Age/Early Bronze Age metalwork from the island which shows affinities with both Irish and early Welsh and Scottish (Migdale) axes, along with the mixing (or recycling) of Ross Island metal with copper from other sources (Timberlake 2009a).

Alderley Edge, Cheshire

In 1874, what was then suggested to be a prehistoric mining landscape (now believed to be of Early Bronze Age date) was uncovered during the course of modern

mining activity at Brynlow (Brynlow Field Opencast within 100m of SJ 855773). This was first recognised by Boyd-Dawkins (1875 & 1876) who inspected the site on numerous occasions in the company of other leading archaeologists of the period. The stone tools retrieved (Fig 2.10 - now in the collections of the Manchester Museum) were later described by Roeder (1901) and Roeder & Graves (1905). An oak shovel, witnessed by Sainter (1878) as having come from one of these early mine pits, and subsequently re-discovered by Alan Garner, was radiocarbon dated in 1994: OxA-4050: 3470 ±90 yrs BP or 1888-1677 yrs cal BC (Garner, et al. 1994). Today the site of this discovery is filled and grassed-over but is still identifiable.

Elsewhere on the Edge, similar mining sites were examined by Roeder (1901) and Roeder & Graves (1905), and then subsequently by Oliver Davies (1935), Carlon (1979), Warrington (1965; 1981) and others. These included, in particular, the Engine Vein (Fig 2.3), but also a site at Dickens Wood and the now-infilled opencast of The Hagg in Windmill Wood, where three slagged sherds of a crucible – illustrated in the Roeder mss – were found. Also, at Mottram St. Andrew approx 1km to the east, Roeder & Graves’ 1905 map indicates the approximate position of the hearth and the hammer stones find. Other sites thought to be prehistoric in origin include Devil’s Grave at Stormy Point and near to West Mine, where workings originally believed to be ‘Roman’ were found in 1858. More recently, those surviving and still recognisable sites, such as Pillar Mine (Dickens Wood, with its three now seriously eroded bisected pit workings, large cave-like entrance and eroding Bronze Age mine spoil), and the Engine Vein opencast to the south (with prehistoric pit workings and the remains of an incipient prehistoric opencut), were re-examined by Pickin (1990; and in Blick 1991), Gale (1989; 1993; 1995), and finally by Timberlake (Timberlake & Prag 2005). Following the survey work carried out by the Alderley Edge Landscape Project in 1997, an archaeological excavation was undertaken of a previously undetected pit-working close to the south-west end of Engine Vein (Fig 2.2). This working, which seems only to have been a prospection undertaken within the mineralised sandstone prior to the main pitting and opencasting on the vein itself, can now be ascribed with some certainty to the period c.100-150 years just before or after 1900 BC (Timberlake & King 2005). Four Early Bronze Age radiocarbon dates were obtained from these excavations, including the charcoal associated with the firesetting and mining of this pit (Beta-115606 3550 ±70 yrs BP or 2035 – 1690 cal BC) and a date for its abandonment, which seems to be consecutive with continued working on the vein. Within the last few years, archaeological evaluation



Figure 2.4 Excavated Bronze Age copper mine in 2009, Trench C2, The Lumb, Ecton Hill, Staffordshire. © Simon Timberlake

work carried out at Stormy Point by the University of Manchester Archaeological Unit, has revealed further evidence for Early Bronze Age, and perhaps also later prehistoric mining in the form of at least two prospection pits, one of which was dated to 1690 – 1510 BC (Mottershead & Wright 2008). However, the absence of open-area excavation here has made it difficult to interpret this site further.

The production of copper (and perhaps small amounts of lead) during this 100-200 year period of Early Bronze Age mining may not have exceeded 20 tons of hand-picked and cobbled (crushed and dressed) ore. Given this relatively small amount, it seems possible that the copper was smelted locally up on the Edge. Although the evidence for this has yet to be found, in 1901 Roeder does refer to hearths at Engine Vein, which may have been roasting beds. Reconstructions of a primitive smelting operation, involving the construction of small ephemeral bowl furnaces fired with charcoal/wood, were undertaken at Alderley Edge during September 1997 and July 1998 (Timberlake 2005c).

Ecton Copper Mine

Stone tools ‘used by the aboriginal miners’ and found within in the Duke of Devonshire’s copper mines at Ecton near Leek in Staffordshire in the 1850s, were displayed in the Derbyshire antiquary Thomas Bateman’s collection

(now at Sheffield Museum). Hammerstones were also found redeposited on old tips at Dutchman Mine by Graham Guilbert in the 1990s. Following underground exploration in 1997, the end of a primitive red deer antler pick was recovered from amongst rock collapsed in from surface workings some 20-30m underground near the top of Dutchman or Stone Quarry Mine. This provided an Early Bronze Age radiocarbon date (1880–1630 cal BC at 95% probability) suggesting the existence of a second locality for Bronze Age copper mining in England (Barnatt & Thomas 1998; Pickin 1999; Guilbert 1994a; 1994b). The ore deposits here consisted of veins and pipe workings formed from a combination of tight anticlinal folds and faults within Carboniferous Limestone containing chalcopyrite completely oxidised to malachite at surface.

In 2008, the Early Mines Research Group undertook surface excavations at the site of an old opencast and later shafts at Stone Quarry Mine (as part of a Peak District National Park project funded by English Heritage). These revealed evidence for 17th-century AD mining and the backfill of an earlier opencast, but amongst the later mine spoil emptied out from below were some stone hammers and bone tools, some of which were subsequently dated to the period 1800 – 1600 BC. At The Lumb, a few hundred metres away close to the summit of Ecton Hill, a series of shallow horizontal cave-like workings were investigated in 2009. The excavation of a hollow in front of one of these revealed a small outcrop working on a bed of cupriferous dolomitic limestone (Fig 2.4). This horizon appeared to have been mined in prehistory with bone and stone hammers, before being re-worked in the post-medieval period. Some preserved lenses of early mine spoil containing *in situ* flakes of bone and antler were encountered amongst this; this included the tip of a worked antler tool, which gave the following date: OxA-21507 3445 ± 28 1880–1680 cal BC (at 95% confidence). Since that time, twelve bone tools (points and scrapers) from The Lumb and Stone Quarry mines have been dated and the results have been Bayesian modelled in an attempt to establish the period and sequence of working (see appendix Tables 1 and 2). It seems probable from this that Stone Quarry was mined first (and perhaps for longer) in the Early Bronze Age, followed by The Lumb, the latter perhaps as a prospection (this included one Middle Bronze Age dated bone tool). The bone tools (Fig 2.5) were mostly made from split cattle tibia (rather similar to the tools found on the Great Orme, Llandudno), whilst the majority of the hammerstones (Fig 2.6) were hand-held, un-modified river cobbles collected from the bed of the River Manifold at the base of Ecton Hill. No traces of an accompanying mining camp, or for that matter, nearby traces of processing or smelting, were found.



Figure 2.5 Broken end of cow tibia used as a Bronze Age mining tool, The Lumb, Ecton, Staffordshire. © Simon Timberlake



Figure 2.6 Hand-held hammerstone for mining and crushing, Trench C2, The Lumb, Ecton, Staffordshire. © Simon Timberlake

2.3.2 Iron Age

Currently, there is little site-based evidence for Iron Age copper mining in the British Isles. One very likely site, but one for which we have no dating evidence from the mine itself, is Llanymynech Ogof (SJ 265 222). This Carboniferous Limestone hill straddles the border between England and Wales.

Reputed in the 19th century to have been a Roman mine, on account of the find(s) of Roman coins and a coin hoard buried within mining deads underground, this small, and now well surveyed and explored, labyrinthine system of mine passages seems much more likely to be Iron Age, or earlier, in date. Antler pick tools have been found underground (Adams 1970), and a single round hammerstone within the entrance passage (Timberlake 1996). Most important of all was the result of a palaeo-environmental study; the coring of a peat basin within the Iron Age hillfort (which also encloses the site of the mine) has revealed evidence for mining or smelting-related copper pollution, which corresponds in date with the occupation of this site (Moore 1992). In 1981, excavation of a pipe trench through the hillfort rampart revealed two metalworking (bowl) hearths and a pit associated with the crude working of copper dating to the period 275 – 10 BC (Thorburn 1988), and further hearths were discovered in the early 1990s (Musson et al. 1989). More recently, an excavation at Downgay Lane, Four Crosses (within a few kilometres of Llanymynech) uncovered a Middle Iron Age copper smelting site containing 13 furnaces with some of the earliest examples for the use of tuyeres in the UK (this is as yet unpublished). The lead and zinc-rich copper from here provides a reasonable match with the malachite ore from, or of, Llanymynech Ogof (T Young *pers comm*).

2.3.3 Roman

Alderley Edge: Pot Shaft

In March 1995, an early 4th-century AD coin hoard (Fig 2.8), consisting of 256 bronze coins contained within a pot, was found in the top of an infilled, and previously unknown, shaft on Engine Vein (Nevell 1996). Following this discovery, the full excavation of this shaft was undertaken by the Derbyshire Caving Club in conjunction with the Alderley Edge Landscape Project (Manchester Museum) in October 1997 (Timberlake & Kidd 2005). This work revealed a 12m-deep abandoned Roman shaft and cross-cut level, which connected to the open stope of Engine Vein (see Timberlake & Prag 2005). The 2m by 2m square shaft (Fig 2.7) is large by Roman standards, yet the method of sinking it, and of driving the 7m long level from its base, shows clear similarities with Roman workings recorded in Spain and elsewhere. Although the discovery of a Roman shaft dating from the first half of the 1st century AD is unique to Britain, the style of coarse pick-work upon the walls is reminiscent of that witnessed in the Roman Penlanwen Adit(s) at the Dolaucothi gold mine in South Wales (Manning 1968).

At Engine Vein, it is believed that the shaft was used as a means of laddered access into a slightly larger series of underground workings excavated upon the vein itself. Another similar shaft, of which only two corners and an edge remain, is to be found some 20m away from Pot Shaft on the southern side of the main Engine Vein opencut at SJ 86057748. The latter appears to be associated with an inclined walk-way cut through the rock, as well as with slots cut into the side of a rock ledge some metres back from the shaft. These were for the purposes of fixing what could have been a primitive wooden windlass or capstan, suggesting that this may

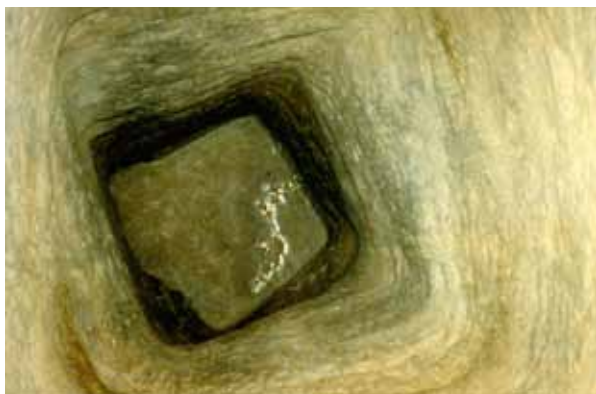


Figure 2.7 View down the 11m-deep excavated Roman mine shaft (Pot Shaft) at Engine Vein, Alderley Edge, Cheshire. © Simon Timberlake



Figure 2.8 Hoard of Roman coins dating from the first half of the fourth century AD, retrieved from Alderley Edge, on the day of discovery in 1995. © Nigel Dibben

have been a haulage shaft. Another 20-30m to the east, and preserved within the north wall of the opencut, are traces of what may be another shaft and a gallery, the latter truncating the bisected hollows (pits) associated with the earlier Bronze Age workings.

Unfortunately, there is, as yet, no conclusive evidence that any of these other features described are actually Roman in date. Nor is there any evidence for an adit level associated with the above workings, nor of surface spreads of Roman mine spoil, nor any archaeological evidence for the foundations of buildings or processing areas, which one might presume to find associated. Therefore, it seems possible that the Roman activity at Engine Vein never amounted to much; perhaps a small mine or trial dug to properly sample this vein for copper (or for lead and silver), the tactic being to test the unexploited vein lying beneath the earlier Bronze Age workings.

The range of radiocarbon dates obtained from the *in situ* timbers found within the base of Pot Shaft do not preclude a Late Pre-Roman Iron Age date for the working, yet based upon the style of mining, an early date seems less likely. In fact, the date for the use of this wood could easily be early Roman (mid-1st century AD), if one assumes that the radiocarbon dated sample of the basal-sawn oak timber included the heartwood (Beta 115611: 2120 ±60 yrs BP [360-280 Cal BC or 250 - 12 Cal BC/AD]). Unfortunately, dendro-chronological dating undertaken on this wood proved unsuccessful, and no Roman pottery or other artefacts were recovered from this working. Mining could have been carried out here under military control, perhaps even by the XX Legion from their base at Chester (Timberlake & Kidd 2005, 94), but in any event, was probably only a short-lived affair, lasting little more than 20 years.

This shaft and level make up the most complete archaeologically excavated Roman mining (feature) in England²

2.4 Tin

2.4.1 Bronze Age

It seems highly probable that alluvial tin (as pebbles-sand consisting of cassiterite) was being exploited during the Bronze Age from the tin-rich areas of Cornwall and Devon. However, the only convincing evidence that we have of local extraction in the Early Bronze Age is of seven fragments of tin slag associated with a dagger within the basal layer of turves of the Caerloggas I Barrow at St. Austell; the samples demonstrate an inefficient smelting of local tin carried out in the 16th century BC (Miles 1975; Salter 1997); there is also the excavated find of cassiterite pebbles at the Bronze Age settlement of Trevisker. The latter seems quite typical of the cassiterite of Goss Moor from which the alluvial tin found in the Lanherne Valley (which could be extracted in prehistory) seems to be derived (Penhallurick 1997). Penhallurick (1986) mentions over 40 prehistoric artefacts recovered from later tin streaming activities, some of which he considers could be objects left by Bronze Age tanners, since the very same tin gravels are more than likely to have been worked again. He lists a number of tin streams around the margins (of the source) granites that he considers may have been worked in prehistory. Foremost are those around St. Austell, in particular the Pentewan Valley, St. Erth and Marazion, and Treloy in St. Columb Minor. A Late Bronze Age hut on Dean Moor, Devon had haematite within its walls which had been separated out from tin ore collected for smelting. More recently, slags have been retrieved from domestic sites at Goldherring and Killigrew (see Section 8), and the early results of yet to be published geo-chemical sampling, have indicated strong elevations of tin deposition in Dartmoor peat in the prehistoric period (Meharg 2011, 1-11).

Excavations of a cist on Dartmoor in 2011 resulted

in the recovery of many small artefacts, including 32 beads of tin, which were part of a bracelet (Fig 2.9). Initial radiocarbon analysis provided an Early Bronze Age date for the burial (i.e. 1900-1500BC). Despite Dartmoor being rich in tin deposits, this is the first tin item to have been retrieved from a prehistoric context (Jones et al. *forthcoming*).

2.4.2 Iron Age

It has been assumed from classical sources (reference to the Cassiterides (islands) and to Ictis by Diodorus (Penhallurick 1986)) that tin was exploited in Cornwall and traded with the Continent by at least the Late Iron Age (Todd 1987). It is likely that such activity dates from even earlier, especially when the early presence of trading sites around the coast by at least the Late Bronze Age is considered (places suggested for the site of Ictis include St. Michael's Mount (4th-1st century AD) and Mount Batten, Plymouth (from c.500 BC). Excavations at Chun Castle showed that tin smelting was being carried out here in the pre-Roman Iron Age (3rd-2nd century BC); probably an indication of local exploitation of tin (Tylecote 1986). Other similar sites include Trevelgue and the Iron Age settlement of Saint Eval.

2.4.3 Roman

Tin exploitation from placer deposits certainly continued during the Roman period as suggested by the assemblage of ingots recovered from Cornish sites such as the Late Roman example from Trethurgy (Quinnell, 2004) stamped with helmeted heads (Todd 1987). A group of plano-convex tin ingots found in 1991-2 from Bigbury Bay, South Devon (thought to be Late Roman (4th–5th century AD) in date on the basis of accompanying amphorae) may relate to contemporary trade and a link with an early Dartmoor tin industry (Fox 1996). The tin streaming at Pentewan, St Austell



Figure 2.9 Tin beads retrieved from an Early Bronze Age burial cist on Dartmoor. © Dartmoor National Park

has likewise turned up Roman artefacts, as has Treloy in St. Columb Minor, where a Roman tin bowl was discovered in 1826. However, given the sheer focused intensity of placer tin exploitation in recent centuries, it is generally accepted as unlikely that physical remains of prehistoric or Roman workings of this type survive. Recent examination of Devon's river sediments, away from the moorland, has provided radiocarbon dates suggesting that wastes from tinworking processes on Dartmoor were being deposited in the rivers in both the Roman and post-Roman periods (Thorndycraft et al. 2004).

2.5 Gold (Cornwall)

2.5.1 Bronze Age

Penhallurick (1986) emphasises the regular recovery by tanners (during the historic period) of small amounts of gold from tin ground at Treloy and within the Carnon Valley. Whilst there seems to be strong circumstantial evidence for prehistoric tin working in these valleys, this alone is not sufficient evidence to suggest these sites as an English Bronze Age gold source. More interesting is the fact that 90% of British Bronze Age goldwork contains small quantities of tin in parts per million; yet samples of Irish, Welsh and Scottish native gold are either devoid or very low in tin (Taylor, 1980). Cornish gold has been shown by Penhallurick (1986) to contain between 25-50ppm tin, whilst analysis of the two Early Bronze Age gold lunulae from Harlyn Bay, Padstow revealed concentrations of 50ppm and 950ppm tin, and that from Saint Juliot 650ppm tin. It seems possible, therefore, that gold was produced as a byproduct of alluvial tin working from the Bronze Age onwards, perhaps in the Carnon Valley.

Some work is currently being undertaken on trace element composition of native gold and Bronze Age gold artifacts in Ireland, with a view to identifying sources (Warner et al. 2010), but very little is being attempted in England or the rest of the UK. Because of the purity of alluvial gold (93% Au), trace element studies as well as studies of stable isotope ratios may prove quite effective in provenancing.

2.6 Lead and Silver

2.6.1 Bronze Age

Southwest England

Burgess and Northover (Tylecote 1986, 27, 30) suggest that lead was being intentionally added to tin bronze during the Acton Park (Middle Bronze Age 1400-1300 BC) and Wilburton (Late Bronze Age 1000-900 BC) metalwork periods, presumably from British sources,

though it was not until the advent of systematic stable lead isotope analysis of bronze artifacts and ores (Rohl & Needham 1998) that a possible match could be suggested between Wilburton metalwork and a lead source in the Mendips, Somerset. Although this cannot be verified, or a specific site identified, this level of provenancing is at least useful in establishing the origins of lead extraction.

Peak District

The discovery at Mam Tor of a Late Bronze Age socketed axe made of lead (Guilbert 1996), might represent the very earliest exploitation of this metal in the Peak. A lead 'torc-end', as yet not fully published, was found in a pit at the centre of a large round house, both with Early Iron Age radiocarbon dates. This was at Gardom's Edge above Baslow on the Peak's eastern gritstone moors, during extensive excavations undertaken by the Peak District National Park Authority and Sheffield University in 1995-2000 (Barnatt et al. 2002; J Barnatt *pers comm*). Late Bronze Age axes from Britain containing up to 15-21% lead are all thought to have an indigenous source (Northover 1980).

Shropshire

Bronze Age mining, including for lead, has also been argued for Llanymynech on the Welsh-Shropshire border (CPAT HER PRN 23399).

2.6.2 Iron Age

Mendips

Todd (1996; 2007) has suggested pre-Roman (Iron Age) mining of lead at Charterhouse-on-Mendip on the basis of finds of a 3rd-century BC Greek coin, a denarius of Julius Caesar, plus Iron Age pottery from excavation trenches sampling 'Roman' mining rakes (opencuts) on the edge of the Charterhouse Roman fortlet undertaken in between 1993-5.

2.6.3 Roman

Lead was used to produce plumbing and water management systems, coffins, lead glass and spindle weights. It was alloyed with tin to produce pewter, and lead compounds were a common adulterant in wine and cosmetics. Numerous Roman pigs of lead have been found on routes leading from the orefields towards ports, from where lead was exported to other parts of the empire, and a Roman shipwreck at Ploumanac'h in Brittany yielded a cargo of British lead pigs from the 2nd to 4th century AD (L'Hour 1987).

Mendips

Roman mining can be confirmed at Charterhouse-on-

Mendip following excavations by Todd (1996; 2007), whilst mining elsewhere in Mendip is suggested by finds of Roman lead smelting slag within a Roman enclosure just east of Priddy at Green Ore, where a 4 ha area is covered by slag, lead fragments and Roman pottery (Todd *ibid*). The large, 100m-long and c.10m-deep, opencut mining rakes on Ubley Warren near Charterhouse are also likely examples. Evidence so far obtained suggests that the latter area, though not archaeologically investigated, produced most of the Roman lead ingot finds in the Mendip. Excavations from 1993, close to the Roman fortlet, revealed evidence for mining during the period AD 50-80, based on pottery finds (Todd 2007, 68).

Todd's excavation results also suggest the possible survival of *in situ* mining features and likely smelting hearths dating from the early Roman period and possible 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 a better planned and larger scale excavation. Given the silver content of these ores, the Mendip Hills is also an area to look for evidence of silver-extraction by cupellation (see Ashworth 1970, 15).

Combe Martin

Combe Martin is known to have been a source of lead and silver from at least the medieval period, but recently this location has yielded finds of Roman pottery and a stylus from beneath a considerable depth of deposits at least partially derived from mining (T Dunkerly *pers comm*). Such evidence, slim though it is, may be indicative of Roman working.

Calstock

Excavation of the recently discovered Roman fort at Calstock (a medieval silver mining/ smelting centre) revealed a layer of mineral vein spoil within the Roman ditch and a Roman furnace, which, it has been suggested, may be associated with smelting. Analyses are awaited.³

Alderley Edge

It is distinctly possible that the substantial, but somewhat sandy or silicic, lead vein at Engine Vein was the goal of the Roman miners when sinking Pot Shaft (Timberlake & Kidd 2005). There would have been a significant demand for lead as pans for use in the Roman salt industry, centred around Nantwich and Middlewich in Cheshire.

Peak District

No direct evidence of Roman mining is forthcoming, though numerous finds of lead pigs (cf LUTUDARUM) suggests some local production, presumably by private

concessionaires rather than under military control. The Matlock area has been suggested as a location for this activity (Tyler 1982); possibly mining was organised here by the mid-late 1st century AD (Boon 1971). A trench dug to investigate a 2nd-century AD field wall at Roystone Grange located a small buried 'scrin' or opencast (Barnatt & Rieuwerts 1998), though a more recent re-evaluation has brought the Roman dating of the boundary into question (Barnatt 1999). No Roman bole smelting hearths have been identified within the mining areas, though a lead smelting hearth associated with a late Roman villa has been identified at Scarcliffe Park near Duffield on the Nottinghamshire-Derbyshire border (Willies 1982; Craddock 1995).

Excavation and dating of some of the numerous lead bole sites in the Peaks may be an easier way to help identify the probable locations of Roman and early medieval mining and could reveal how closely these are related.

Shropshire

During working of the Roman Gravels Mine (Shelve district) in the 19th century, Roman coins, tools (wooden shovels) and considerable traces of stepped opencast workings linked to underground galleries and shafts were found and described (Wright 1862; Tyler 1982). The 'find' of a pig recorded at Roman Gravels is unlikely to be genuine; it occurred about the same time as the 'Roman' was added to the mine's name and has the hallmark of a way of creating interest in shares in the mine. At least three Roman lead pigs have been found in Shropshire, which are accepted as being of local lead, and there have been other pigs found out of the county, which could have been produced in Shropshire. Openworks are still accessible at Roman Gravels, if overgrown, and as yet they are undated (Shaw 2009, 13). It is known that the cupellation of silver was practiced on the Shropshire/Welsh border at Pentrehyling (Bayley & Eckstein 1998). Roman and earlier mining in Shropshire has been researched by R White (2000).

County Durham

The only field evidence for Roman period lead mining in County Durham is circumstantial, in the form of artefact finds from Slitt Mine, Westgate. A hoard of nine silver *denarii* of Vespasian, Antoninus Pius, Hadrian, Faustina I, Marcus Aurelius, Lucilla and Trajan (date range AD 98-141) was apparently found on the edge of an openwork on the Slitt Vein (described as 'near the quarry workings'). The description of the find spot is open to interpretation (hoard deposited in abandoned working, mine contemporary with hoard, or hoard in secondary context and displaced by later mining?)



Figure 2.10 Grooved stone mining hammer from Engine Vein, Alderley Edge. © Simon Timberlake and The Manchester Museum

and would benefit from re-examination. A hoard with a similar date range was discovered in the same general area at High Westgate in the 1870s. Slitt Vein is the longest and one of the strongest lead veins in Weardale and outcrops at surface along much of its length. At Slitt Mine the vein is cut and exposed by the valley of the Middlehope burn, so a good location for early prospection/mining (*Archaeologia Aeliana* 1925, 24; Burnett et al. 1986).

The Roman economy of the South Pennines has been thoroughly explored by Dearne, who focussed in particular on the lead industry (Dearne, 1990).

Alston, Cumbria

Mining here, it is claimed, was carried out by the second cohort of Nervians during the 3rd century AD (Webster 1952). Whatever the nature of this evidence, the recent excavation of a lead smelting furnace within the industrial zone adjacent to Carlisle Roman Fort is probably linked, in some way, to lead from the Alston orefield (Murphy & Zant *forthcoming*).

2.7 Zinc

2.7.1 Roman

Mendips

No evidence of this survives in the UK, but given the mining of lead from these veins, it seems possible that the abundant near-surface calamine (smithsonite or zinc carbonate) ores were exploited by the Romans for the purposes of making brass using the cementation method.

2.8 Iron

2.8.1 Iron Age

In the archaeological record, the evidence for iron extraction is chiefly to be found in the remains of smelting furnaces, the original sources of ore being identified on the basis of ore samples found with the furnace remains. Here we see a development in Britain from the bowl furnace, to shaft furnace, to slag pit furnace (Tylecote 1986). The occurrence of iron smelting at sites away from known sources of iron ore (e.g. Mucking in Essex, Hovingham in Norfolk) attests either to the movement of ore or else to the once fairly universal occurrence of bog iron. Geological sources of iron ore are also fairly widespread: from vein haematite and goethite (Furness in Cumbria; Brendon Hills, Somerset; Forest of Dean), to blackband (siderite) ironstones ubiquitous within the coalfield areas of Britain, Wealden ironstones (siderite) from Sussex, Hampshire and Surrey, and the Cretaceous Greensand (Carstone of Bedfordshire etc, and Upper Greensand ores of Devon).

Dorset

At Hengistbury Head locally collected iron ore was extracted from outcrops in the cliffs and smelted between 400BC and AD 50 (Bushe-Foxe 1915). Similar evidence for locally sourced iron ore and smelting, comes from Gussage All Saints (Wainwright et al. 1979).

Wiltshire

Iron ore was smelted at All Cannings Cross, Wiltshire, between 400-250 BC, using ore from the local Lower Greensand, probably from Seend (Cunnington 1923)

Somerset

A second short rake (opencut) at Charterhouse-on-Mendip examined by Todd in 1996 proved to be for haematite, rather than for lead, and from it a *denarii* of Julius Caesar (48 BC) plus some Iron Age pottery was recovered. Elsewhere, other potential Iron Age mineworkings are poorly explored and often undated; these include potential sites at Kitnor Heath on Exmoor and Colton Pits in the Brendon Hills (L Bray *pers comm*)

Devon

A smelting site, contained within a large round house at Kestor near Chagford in Devon, was previously dated to after 400 BC (Tylecote 1986), but a recently obtained radiocarbon date, places the ironworking activity much later, between the early 5th to early 7th century AD (P Crew *in lit* 27-Oct-2013). The roundhouse nevertheless certainly has its origins in the Iron Age or earlier.

Cornwall

One of the earliest iron extraction sites in this county is at the promontory fort of Trevelgue Head where, within the Mid- and Late Iron Age, between 1.5 and 2.3 tonnes of iron were produced. This is likely to have been extracted from a narrow lode running through the headland on which the site is located (Dungworth 2011). The low level of iron production is notable on this site, which amounts to between 10 and 20 kg of iron, or 2 to 3 smelts each year. This suggests that the scale of Iron Age extraction was limited and that we are unlikely to identify sites of this type, unless they were exploited for significant periods. However, further west, trace element analysis has identified the Great Perran Lode as a potential early source of iron ores (Ehrenreich 1985, 97-99), suggesting future searches for extractive sites here could bear fruit.

Surrey

The site of Brooklands near Weybridge, produced up to 44kg of slag as part of the waste from slag-tapping furnace(s) operated between the early - late Iron Age (from the 5th century BC to 1st century AD); the source of the ore used was probably high-quality sideritic ironstone, outcropping at the nearby Saint George's Hill (Hanworth & Tomalin 1977). At Purberry Shot near Ewell, furnace bases, and a bloom dating from 200 BC – AD 150, represent a small industry using local iron ores from the Wadhurst Clay (Lowther 1946).

Sussex

Pre-Roman iron smelting (190-80 BC) in shaft furnaces with slag-tapping pits has been identified at Broadfield near Crawley in Sussex (Gibson-Hill 1980), where local Wealden iron ores (siderite) were used. As well as smelting, local Wealden Iron Age bloomery sites have been investigated, such as at Crowhurst Park, Bardown and Chitcomb (Tylecote 1986).

East Anglia

Iron smelting as well as ironworking has been encountered at recently excavated fenland edge Iron Age settlements, such as at Bradley Fen, Cambridgeshire (Gibson & Knight *forthcoming*), possibly exploiting local bog iron ores, or else Northamptonshire ironstone, which may have been sourced from the southern part of the East Midlands orefield (Fincham 2004).

Northamptonshire

Associated with the settlement at Hunsbury were pits containing a significant amount of iron slag, suggesting smelting operations using the local Northamptonshire ironstone (Jackson 1993-4, 35-46). Other Iron Age furnaces have been found at Wakerley (Tylecote 1986).

Perhaps one of the most interesting recent case studies relates to excavations of seven slag-tapping furnaces, found during investigations adjacent to a Roman villa at Priors Hall, Corby (*British Archaeology* 98, Jan/Feb 2008). Later Iron Age pottery (100 BC – AD 43) and tuyere fragments were recovered; they represent, perhaps the best preserved examples of Late Iron Age furnaces, complete with tapping arches and pits, and furnace superstructure. The local Northamptonshire ironstone is likely to have been smelted, most probably from outcrops within the area of Rockingham Forest.

East Yorkshire

The spectacular Middle Iron Age 'Arras Culture,' linked to important chariot burials and the excavation of the Hasholme log boat, was home to one of Britain's largest prehistoric iron industries dating from around 300 BC. The iron industry appears to be based on large deposits of bog iron ore within the coastal Foulness Valley south of Holme, Humberside⁴ Furnaces, and large quantities of iron slag from the smelting of these sandy bog iron ores, have been excavated at Whelham Bridge, Yorkshire (Halkon & Millet 1999).

Northern England

Early Iron Age (7th-6th century BC) furnaces have been found at West Brandon in Durham (Jobey 1962), and at Roxby in Cleveland (Spratt & Inman 1986), the latter exploiting the local Cleveland iron ore.

2.8.2 Roman

Cornwall

Restormel Roman Fort is located close to an important iron vein (Restormel iron lode).⁵

Blackdown Hills, Devon

A landscape of early iron extraction pits can be seen at Hemyock near Upottery on the River Otter in the Blackdown Hills.⁶ Most of this extraction is undated, but trial archaeological excavations associated with a large-scale survey of the deposits identified smelting sites dating to the Saxon and Roman periods. Pottery from these layers produced a date in the second half of the 1st century AD (AD 50-70), a date which suggests Roman military control, or an overview of exploitation centered perhaps on the legionary fortress at Exeter (Griffith & Weddell 1996). Iron ore, geologically similar

to that from the Blackdowns, was recovered during excavation of the Roman fort at Bolham, Devon (Maxfield, 1991).

Exmoor

Iron production grew from the beginning of the 2nd century AD, reaching substantial levels on sites on the southern fringes of Exmoor such as Sherracombe Ford and Brayford. More recently, a Late Roman smelting site has been identified at Blacklake Wood as part of the Exmoor Iron Project (ExFe) under the leadership of Gill Juleff at the University of Exeter. Sites have been identified through geophysics (magnetometer and magnetic susceptibility), geochemical (PXRF) survey (Carey 2005), and then archaeologically excavated and dated (Bray 2002). A number of complementary scientific approaches have also been tried in this area (Dean 2003; Brown et al. 2009; Fyfe 2003; 2009; Karloukovski & Hounslow 2006). The suggested source of much of the Roman iron smelting seen in this area is 'Roman Lode' at Burcombe near Simonsbath. The anciently worked lode (goethite) is over 600m long and is opencasted to a depth of over 5m. (Fletcher et al. 1997). Excavations at this site have been carried out by Bray (2002; 2006b).

Somerset

At Treborough and Luxborough there is evidence of Roman extraction of iron ore at outcrop (Yates 1858). Roman exploitation of the haematite ores of the Brendon Hills has been suggested at Colton Pits, though there is no datable evidence (L Bray *pers comm*), and at Clatworthy Reservoir, samian pottery scatters have been found in the vicinity of bloomery slag heaps.

Gloucestershire

At Lydney (Wheeler 1932), a small underground working of iron ore (goethite) was located, where a band of ferruginous marl was worked, and later sealed by a 3rd century AD hut (see also Scott-Garrett 1959).

Forest of Dean

Ancient opencast workings known, as *scowles*, are relatively commonplace in the Forest (Fig 4.1). These represent worked-out, surface portions of iron veins, and also solution-filled (iron ore) cavities within the limestone. In some cases these can be traced for several kilometers and represent massive iron ore extractions. Almost all are undated but, given the examples of pottery and coins unearthed (as at ancient iron smelting sites near Whitchurch, and mining and smelting sites at Tidenham, Coppet Wood Hill, Perry Grove and Crabtree Hill), and the nearby Roman iron-smelting settlement of Ariconium, it is more than likely that some of these at least are Romano-British in origin

(Nicholls 1866). Finds from some of the other sites suggest early medieval working (Nicholls 1986). The classic scowle workings at Puzzle Wood, near Coleford, are thought likely to be Romano-British (Blick 1991). A general summary of the topic has been attempted by Wildgoose (1993).

From the 3rd century AD, a reduction in the size of iron production sites is apparent in Britain, and a concomitant decrease in the scale of extraction can be expected, although no workings are currently known from this date. The exception to this is the Forest of Dean, where iron production increased during the later Roman period.

Northamptonshire

The fact that large numbers of smithing furnaces were found at *Corstopitum* (Roman Corbridge), though little evidence of smelting in the form of slag, might suggest that the Roman military did not bother to smelt iron themselves, but instead relied on British smelters (Tylecote 1986). However, there is evidence of domestic smelting of iron within this iron-producing region of the Midlands, particularly in 2nd–3rd century villas such as Great Weldon (*British Archaeology* 98, Jan/Feb 2008). The Northamptonshire ironstone was worked from shallow surface outcrops by means of opencasts. Smelting furnaces at Kings Cliff near Bulwick lie close to possible workings (Jackson 1979, 31-7). Traces of these workings within the Northamptonshire orefield have been found at Oundle and Laxton (Taylor & Collingwood 1926).

Lincolnshire

Roman iron smelting remains have been found at Pickworth, Bagmoor, Colsterworth, Thealby, and Claxby; these smelting locations lie within the area of iron mining and outcrops of the Northamptonshire ironstone (Cooper Key 1896).

Norfolk

At Ashwicken, nodular iron ore was obtained by extraction pits over a horizon within the Lower Greensand (carstone) some 3m - 13m deep (Tylecote 1967). These minepit workings cut through Boulder Clay down to the Lower Greensand, the clay being used in the construction of tree-trunk pattern moulded furnaces for smelting in the immediate locality. These formed some of the best shaft smelting furnaces seen in Roman Britain (dated 2nd century AD). Large slag cakes found at Hevingham also suggest local smelting.

Sussex

Wealden iron ore (nodular siderite and occasionally limonite) was extracted by means of pits. These were noted at Minepit Wood in Sussex, and associated with smelting furnaces (possibly a bowl furnace type)

dating from the 1st-2nd century AD (Money 1974). The furnaces were charged with a mixture of siderite and oak charcoal – the siderite came from the Wadhurst Clay exposed within the immediate vicinity. Other Wealden Roman furnaces have been found within the same area at Cow Park and Pippingford, Hartfield, and also at Holbeanwood and Broadfield near Crawley (Cleere 1970 and Tebbut and Cleere 1973). Romano-British iron production in the Weald has been reviewed by Hodgkinson (1999).

Recent archaeological excavations, and reconstructions of Roman iron smelting furnaces, have been undertaken and recorded by the Wealden Iron Research Group (WIRG) founded by Cleere and Crossley in 1968.⁷

Northern England

Both ore and slag are associated with smelting remains at the Roman fort of Templebrough near Rotherham, Yorkshire, whilst the fort of Galava at Ambleside produced evidence of the smelting of local bog iron ores (Tylecote 1986).

2.9 Fossil minerals

2.9.1 Coal

Iron Age

Evidence for the very early (7th-6th century BC) use of coal as fuel in iron smithing operations, comes from the palisaded site of Huckhoe in Northumberland (Smith 1905). A piece of part-welded iron was associated with a large quantity of coal within the hearth. The source of the coal is not known, though local surface outcrops abound nearby. This example seems, so far, to be unique for prehistoric Britain.

Roman

There is evidence for the use of coal in a military context for domestic heating and perhaps also iron smithing, within the northern forts on the Antonine Wall, and Hadrian's Wall (with possible sources as outcrop workings in the Northumbrian and Midlothian coalfields). In particular, the use of coal is reported in the archaeological literature at Housesteads and Corbridge fort(s), as well as at Chester and Manchester (Preece & Ellis 1981). Contemporary documents suggest the use of coal to maintain the perpetual fire at the Temple of Minerva in Bath (*Aquae Sulis*). It would seem that there was one cluster of coal use in Roman Britain within the Flint-Chester area (perhaps with a source in the North Wales coalfield), and another in the area of the Bristol Channel area, and then south east as far as Silbury Hill

(source in the South Wales and Bristol and Somerset coalfields). The final cluster is to be found in East Anglia between Cambridge and The Wash. These sites lie 200 miles by sea, and 40 miles by land, from the nearest coalfield sources. The distribution of sites might relate to their proximity to the Roman Car Dyke from The Wash to near Cambridge. Coal may have been brought by sea from Yorkshire or Northumberland, in much the same way sea coal was extracted and then brought by sea and canal to Cambridge and the other East Anglian towns (Preece & Ellis 1981, 17). Small quantities of coal were found at Roman Wroxeter and Meole Brace, both in Shropshire, though whether the coal was from what was to become the Shrewsbury coalfield, or from the Coalbrookdale area, cannot be established, but in each case coal was later mined in the vicinity (Ellis 2000; Evans 1999).

In the most recent study of Roman coal, Travis has provided a persuasive argument for coal mining to have taken place in many areas of Britain in the Romano-British period; this is based on secondary finds and coal residues retrieved from a number of non-mining sites, confirming extensive coal usage. He was also able to provenance some samples of coal taken from Roman contexts to specific seams. However, such is the elusiveness of the evidence, that the work was unsuccessful in identifying the site of a single Roman coal mine (Travis 2008).

The only putative Roman coal extraction site listed in the EH Coal Industry MPP Assessment (Gould & Cranstone 1993) is Stratton Common, near Stratton on the Fosse in Avon. Apparently, anciently worked coal outcrops here provide the nearest source of coal to Roman Bath on the Roman road network (the worked area straddles the main road to Bath). Documented mining began here in 1300 AD, but it seems likely that the mine had much earlier origins (Down & Warrington 1971, 224-6).

2.9.2 Oil Shale

There is evidence for this (Kimmeridge Shale) being used as a fuel in Iron Age salt production (boiling and evaporation of brine in briquetage pans) at Kimmeridge in Dorset (D Cranstone *pers comm*)

2.9.3 Peat

Roman salterns (salt working sites) within Essex, Cambridgeshire, Norfolk and Lincolnshire may have used peat as a fuel for boiling and evaporating brine within briquetage pans (Lane & Morris 2001).



Figure 2.11 Front and reverse views of a jet button, retrieved from an Early Bronze Age, Devon Barrow. This item was formerly believed to have been made from Kimmeridge shale, but recent analysis by Plymouth City Museum has confirmed it is of jet. James Davies, © Historic England

2.9.4 Jet

In effect, almost all true jet used in Britain, from the Bronze Age to the Roman Period, originated in the Whitby coastline of North Yorkshire. Much of this jet may have originally been sea-washed pieces eroded out of the Upper Lias (Lower Jurassic) shales (specifically the thin Upper and Lower Jet Beds), which make up part of the strata of these cliffs. Bead production could have been assisted by mining the thinnest laminae of jet fresh from the shales themselves. Extractive sites of this period have not yet been identified.

Prehistoric

Jet is an important grave good (as jet buttons or necklaces of small beads and spacers) accompanying inhumation burials within Early Bronze Age barrows (Fig 2.11). X-Ray Fluorescence analysis of all 117 pieces of the Kill y Kiaran necklace, found within a barrow burial in Scotland, suggests that all but 24 of these beads were made of Whitby jet.⁸

It seems possible that the remaining ones could have been of cannel coal – a similarly indurated form of mineral coal, which does, nevertheless, have an inferior lustre. Cannel coal was sometimes used for making bracelets and beads. Sources for this includes the Lias of the Dorset coast.

Roman

Jet was used in a similar fashion to prehistoric burials; in this case female individuals were accompanied by jet jewellery in the case of inhumation and sometimes coffined burials of rich individuals. The products of the industry have been researched and provenance of some Roman finds assigned to the Whitby area, with a possible specialist centre at South Shields (Allason Jones & Jones 1994; Allason Jones 2002). Extractive sites of this period are yet to be identified.

2.9.5 Amber

Prehistoric and Roman

Sources of amber used in prehistory as jewellery (within Early Bronze Age burials), are almost certainly from beach collection along the east coast of Britain, especially East Anglia. The original source for this is likely to be the Baltic – the fossil resin being washed out, then floating across the North Sea.

2.10 Flint

The use of flint for tools and other artefacts, (excluding gunflint), is largely restricted to the prehistoric period. Burnt flint is associated with burnt flint mounds, and is used as a temper in pottery, yet its main specific use is as worked flint tools, either as flakes (blades and scrapers), or else as core tools such as axes. Within the Neolithic period, these axes were traded, either as rough-outs or as polished examples. Opportunistic surface collection in the Mesolithic gave way to the shaft-mining from unweathered/unflawed floorstone flint within the Upper Chalk during the Neolithic. In the latter period, mined flint accounted for a small proportion of the total consumption of the material; the majority was retrieved from natural surface deposits, or from chalk cliffs. Some academics now believe tools fabricated from the best mined flint may have had a ceremonial function beyond any practical purpose (Barber et al. 1999).

Prehistoric flint mining has received a good deal of attention from early researchers including Clark (1911), but more recently, general studies have been published by Holgate (1995) and Russell (2001a). A national survey of the landscape evidence for Neolithic flint mining sites in England by the RCHME, culminated in a monograph (Barber et al. 1999).

2.10.1 Prehistoric

Salisbury Plain

Southwest England did not see intensive flint extraction in the form of mining, except in Wiltshire, where at Easton Down, a complex of more than 200 shafts dating from the Neolithic has been recorded, though with associated Beaker settlement (Wiltshire HER No. SU 23NW 101). It was probably an outlier from mining further east. Other sites within 10 miles of this include Durrington and Martin's Clump, the latter site in Hampshire. Martin's Clump seems to have been an earlier site (4200 – 3700 BC), whilst Easton Down has produced dates from around the end of this period to around 2700 BC (Barber et al. 1999). Chert resources were also exploited, but both flint and chert appear to have been exploited in a more opportunistic, less organised way than further east (*inf* L Bray).

South Downs

The largest, and perhaps earliest, group of Neolithic flint mines is to be found within the Upper Chalk landscape of the South Downs in West Sussex. This forms a line of sites along the downland ridge from Nore Down in the west to Cissbury in the east (Nore Down, Stoke Down, Long Down, Harrow Hill, Blackpatch, Church Hill/ Tolmere Pond, and Cissbury). This area was the subject of aerial reconnaissance in the 1990s (Barber & Dyer 2005). Probably the earliest mines (forming a landscape of single shafts and upcast, loosely following the contours of the hills) are those of Church Hill and Harrow Hill, spanning just over a millennium of the Early Neolithic from 4500 to 3400 BC, contemporary with the construction of the causewayed enclosures. These mines were first excavated by the Curwens in the 1920s (Curwen 1926) and more recently by McNab (1996). The site was re-surveyed by the RCHME in 1998 (Oswald 1998; Barber 1999). The important site of Cissbury in Sussex appears later, commencing around 4000 BC and ending around 2900 BC, the latter date just contemporary with the beginnings of Stonehenge and the earliest Beakers. Cissbury, which is disturbed by later hillfort construction (Field 1994, 22-5), was first excavated by Colonel Lane Fox in 1875, whilst Cissbury, Blackpatch, Church Hill and Harrow Hill were later investigated underground (between 1922 and 1955) by John Pull, whose work has been summarised recently by Russell (2001b). At Cissbury, flint workings included small circular or sub-circular pits, large single shafts, and large paired shafts linked by a common spoil tip. Traces of ladder, antler picks, hand held hammerstones, pottery, and pictograms on the walls of the galleries were noted. Surface quarries first exploited the outcropping flint seams, which were then followed upslope by increasingly deeper shafts – the lower workings becoming buried beneath the spoil of the later shafts. The product of these mines were generally rough-outs of flint axes, many of which, it appears from the evidence of knapping debitage, were knocked up on site.

Norfolk

Two other underground Neolithic flint mines, Buckenham Toft and Grime's Graves (Fig 2.12), form a small group (the Breckland Group) within the Brandon area of Norfolk. Canon Greenwell first worked at Grime's Graves between 1868 and 1870. It was this work, excavating the shafts and galleries, which prompted excavations at similar sites in Sussex. Here, the method of Neolithic mining was to excavate galleries above the preferred floorstone layer, after first excavating down through the other seams, the large flint nodules being prised up from the floor with antler picks. Early 20th-century excavations at this site were



Figure 2.12 Surface evidence of flint mines at Grime's Graves, Norfolk. © Skyscan Balloon Photography/Historic England

published by Clarke (1914), by Armstrong in the 1920-30s, and by Mercer and Sieveking in the 1970s (British Museum). It seems likely that this largest group of Neolithic flint mines (of more than a hundred shafts) is a later phenomenon, only just overlapping with the mining at Cissbury (3000 BC) and finishing after 2000 BC, thus spanning the period of Stonehenge. A range of working types can be identified, from prospection pits to opencast workings, and single or double (paired) shafts. At this late date, the product does not appear to be (polished) flint axes, but possibly quality flint for smaller tools (Craddock et al. 1983). Grime's Graves is an English Heritage guardianship site and has been the focus for much recent archaeological research, including excavations published by Mercer (1981) and Longworth (1986); a large number of specialist fascicules associated with these works have been published (see Section 15.3).

Hampshire

A flint mine at Over Wallop was first reported by Stone (1933, 177-80) but much later Ride (1989, 213-5) suggested that the excavation from a single shaft here has parallels with the Easton Down Mines

Surrey

Two flint mine shafts about 3.65m deep, one Neolithic the other medieval, were excavated at East Horsley in 1949. Two working floors were found associated with the Neolithic mine, with finds including a Campigny type axe, 80 implements, 715 wasters, pot boilers, chalk balls and Neolithic 'A' pottery. A Thames pick was also found (*inf.* Surrey HER 2040; 2643. See also Todd 1950; Wood 1951).

Essex

A flint mine near Grimsditch Wood was listed by Morris in the 1920s, but no further information is available (Morris 1923, 63-4).

Other flint

In the Neolithic and Bronze Age, surface extraction of flint for artefact production is much more widespread; extraction sites are common on the edges of the chalk outcrop on the North and South Downs, the Chilterns, and the chalk of Cambridgeshire, Suffolk and Norfolk, often associated with clay with flint deposits and with flint-filled solution hollows and periglacial features.

The earliest Lower Palaeolithic flint tools (and

thus extraction/collection of flint) has recently been identified and dated (to 800 000 years BP) within interglacial deposits at Happisburgh on the Norfolk coast (Parfitt 2006). At Boxgrove near Chichester, at a hunting and butchering site associated with a raised beach, flint (core) tools dating to 500 000 years BP have been found (Parfitt 2006).

2.11 Polished stone axes

Southwest England – Cornwall

One of the most significant uses of stone in prehistory was for the production of polished stone axes in the early Neolithic. These have a widespread distribution within Britain and can be divided, based on their lithology, into groups, a number of which originate within the Cornwall and Devon peninsula. Mercer (1986), for example, identified nine outcrops in Cornwall that were the sources for the majority of the polished axe assemblage from southern England. The suggestion is that rock types from within the peninsula, especially Cornwall, had cultural significance. The Neolithic settlement of Carn Brea, Camborne produced 18 polished axes made of *Group XVI* rock (an epidiorite or greenstone), the source for which has been identified nearby at Camborne (as yet no actual extraction sites have been identified). Other Cornish axe sources include the greenstones represented by *Groups I* (a uraltised gabbro from Mount's Bay area, Penzance), *IV* (an altered picrite from near Callington), and *XVII* (an epidiorite from St Austell) (Davis et al. in McKClough & Cummins 1988).

Lake District and Northern England

Perhaps the best known of stone axe quarry sites in Britain are the prolific 'factories' to be found in the Great Langdale and Scafell areas of the central Lake District. These have been well studied since the mid-20th century, including work by Flint (1962;1978), Claris et al. (1989), Houlder (1979) and Edmonds (2004). The sought-after rock is an epidotised intermediate tuff of the Borrowdale Volcanic Series, *Group VI* of the British stone implement petrology groups (Keiller et al. 1941). This stone was quarried at outcrop throughout the Later Neolithic, using hammerstones and, occasionally fire; the debris from the quarrying and initial shaping of axe blanks litters the slopes below these outcrops, for example the scree below Stickle Pike. Early investigations of this site were undertaken by Bunch and Fell (1949), but more recently work has been undertaken by Oxford Archaeology North (Anon 2000a). The resulting polished axes from this production account for over 20% of all published stone implement identifications, their distribution being very widespread across Britain,

with some spread of artefacts into Europe.

Other polished stone implements from Cumbria include the axe-hammers and other perforated implements fabricated from micaceous sub-greywackes (*Group XV*), these rocks originate within the southern lakes, but perhaps not at quarry sites. Perforated implements of quartz dolerite have also been identified from the Whin Sill of Northern England (*Group XVIII*), whilst locally distributed axes of a sedimentary rock consisting of carbonate mudstone (*Group XXVI*) can be linked to the Lias of North Yorkshire.

Midlands

Axes and perforated stone implements made of an epidotised ashy grit (*Group XX*) can be linked to Precambrian rock outcrops at Charnwood Forest in Leicestershire, as was the distinctive igneous rock camptonite (*Group XIV*) outcropping near Nuneaton in Warwickshire.

2.12 Building stone (see Section 3)

2.13 Ornamental stone

2.13.1 Southwest England

Prehistoric

Stone was exploited for ornamental purposes. The best example is Kimmeridge shale from Purbeck (Upper Jurassic), which was extracted for the manufacture of personal ornaments in the Iron Age. A group of shale cups has been retrieved from Early Bronze Age barrows across Devon, Dorset and Wiltshire (Soper 1989). As the only source of shale suitable for such uses in Britain, the distribution of objects made from it is very wide reaching, far outside the region.

Roman

Production of stone (limestone) from Purbeck expanded in the Roman period, both in volume and variety, with tableware and furniture parts added to the repertoire of the workers (Sunter & Woodward, 1987). A further example is provided by the *greisen* and *elvan* (quartz porphyry) bowls of Cornwall, which seem to have developed as distinctive, perhaps culturally significant, artefacts among Roman period inhabitants (Quinnell, 2004). However, production was on a very minor local scale and extraction is likely to have left little trace

2.14 Quernstones and worked stone

From the Neolithic to Early to Mid-Iron Age, querns for grinding grain were stationary, saddlequern blocks used for milling on their upper faces with rubbing stones. It is

possible that glacial erratic boulders were used for this purpose. In Southeast England and East Anglia, sarsen stones were often used, but granite or hard crystalline rocks were sometimes preferred, where these were available.

2.14.1 Prehistoric

Southeast England

Rotating hand mills (or rotary querns) were produced and distributed from the quarry source. These mills began to appear in Britain in the Late Iron Age, and from their form, they are known by terms such as the Hunsbury, Sussex, Wessex and Yorkshire types. As regards the stone sources, some of the Sussex beehive querns can be linked to quarries within the Lower Greensand outcrop at Lodsworth in Sussex (Peacock 1987). Querns from this source were traded as far afield as Hampshire, Dorset, Gloucestershire, Bedfordshire and Hertfordshire. Rough-outs, rejects and piles of flaked stone can be found at these quarries. Another quernstone production site on the Greensand can be found in a quarry, at East Wear Bay, Folkestone in Kent (Keller 1988), which flourished in the 1st century BC. By the Later Iron Age and Roman periods, beehive rotary querns were being made from a difficult to work, but very tough, pebble conglomerate rock (*Hertfordshire Puddingstone*), which outcropped at the base of the Eocene, and was quarried extensively at sites such as Abbington Piggotts in Hertfordshire (Peacock 1980). However, by the end of the 1st century AD, the use of these querns was declining in the face of competition from imported lava querns from the Rhineland, and from Northern England, the production of gritstone handmill querns. Excavations at Boxfield Farm, Stevenage, which is local to the puddingstone source, revealed that few of the quernstone fragments were from this source and most were imported from elsewhere, including Niedermendig lava and millstone grit (Williams 1991). In a study by Ingle (1987), Cumbrian sources for beehive querns were considered from millstone grit, Penrith sandstone and granite erratics, together with a discussion on the possibility of production centres.

Central and Northern England

By the end of the 1st century AD, rotary querns made of (Upper Carboniferous) Millstone Grit were being produced at quern quarry sites such as Wharnecliffe, where over 2000 querns were identified in a survey following a heath fire (Pearson 2000), and Rivelin on the outskirts of Sheffield. The use of these querns quickly spread across Roman Britain.

2.14.2 Roman

Southwest England

The Devonian Old Red Sandstone (ORS) is known to have been used to manufacture querns in both the prehistoric and Roman periods (Shaffrey 2006). In the latter, these were rotary quern hand mills. Indeed, finds from Iron Age contexts in Somerset, suggest the aforementioned quarrying of ORS at Beacon Hill near Shepton Mallet may have begun in the prehistoric period in order to supply quernstone manufacture. Other local sources of suitable stone probably existed, one possible example being represented by a quernstone from recent excavations at Cullompton in Devon which appears to have originated from the Upper Greensand of the Blackdown Hills; a rock type that was also exploited during the medieval period for honestone manufacture known as sythestones or 'batts' (Staines 1993). It is likely that local extraction for this purpose was small-scale.

2.15 Clay

2.15.1 Prehistoric

The *gabbroic clays* of the Lizard in West Cornwall were identified by Peacock (1969) as the source of an important Neolithic ceramic fabric. The distribution of pottery in this fabric was regional, extending as far as Windmill Hill and Maiden Castle. However, archaeological evidence of extraction would be extremely difficult to identify for this period.

2.15.2 Roman

The sources of clay used in Roman pottery and tile manufacture are many. These relate to local kiln sites, but also reflect some sort of continuity between Iron Age and Romano-British pottery production. The production of roof, floor and hypocaust tiles from the 1st-2nd century AD onwards, grew in importance as the number of rural villas increased. The production of these was often local to the villa sites, using whatever clay sources were available.

Southeast England

In Cambridgeshire, some important local kiln sites developed on clay outcrops: at Horningsea the pottery kilns were established on an outcrop of *Gault Clay*, whilst at Earith these were established on the Jurassic *Amphill Clay*.

Southwest England

In the Roman period, around 95% of all pottery in Cornwall used *gabbroic clays* (Quinnell 1986, 129).

Exploitation over such a long period of time may have left significant evidence for the nature of its extraction although none has yet been identified. Other places where pottery production may have left traces of clay extraction include South Devon; pottery using a granitic clay was produced here, its distribution extending across Devon and beyond in the Late Roman period. Additionally, various greywares were produced in Somerset and Devon in the Roman period (Holbrook & Bidwell, 1991). These wares are little studied, but seem to have been manufactured in large volumes, again suggesting some intensity of extraction.

2.16 Salt

Apart from the extraction of rock salt (in England, principally, from the Trias Keuper [Mercia Mudstone] evaporite horizons), or else the boiling of natural brines formed from the solution of this mineral, most prehistoric and Roman salt extraction is coastal and linked to the evaporation of sea water. Three main processes were used:

- solar - evaporation from seawater through to salt with no separate concentration
- direct boiling - boiling from seawater through to salt with no prior concentration
- pre-concentration - removal of water or addition of salt to convert seawater to a concentrated brine before boiling.
- In practice these types divide into five separate methods:
- total solar – evaporation from shallow lagoonal ponds
- partial solar – evaporation in the same way but then the resultant concentrated brine boiled dry in pans
- sleeching – the removal of the removal of the salt-encrusted surface of saltmarsh silts, the salt leached out and then boiled
- the panhouse process – saltwater boiled directly within bricketage or else within iron or lead pans
- salt refining – impure salt re-dissolved in sea water or brine, then evaporated to salt crystals.

Prehistoric (Bronze Age and Iron Age) salt extraction in Britain was largely of the pan evaporation type, using bricketage pans for boiling, whilst Roman (Romano-British) production involved both sleeching and pan-type processes.

Iron Age and Roman saltmaking sites are common along parts of the south coast, Essex, the Fens of Cambridgeshire and Lincolnshire; they are identified by finds of fired-clay 'bricketage', kiln furniture, boiling pans, and porous salt-moulds or very coarse pottery (VCP),

although only the kiln furniture and pan fragments are definite production debris. Small quantities of VCP are more likely to represent salt transport or consumption. The process is generally assumed to have been direct boiling of seawater. There is experimental evidence that one particular variant, using hemi-cylindrical boiling vessels on a large rectangular oven works well with direct boiling, but it seems very likely that most bricketage sites used some form of pre-concentration to keep their fuel consumption down. The most useful, and widely used, reference work on this topic is Lane & Morris (2001) *A Millennium of Saltmaking: Prehistoric and Romano-British Salt Production in the Fenland*.

Inland salt production during the prehistoric to Romano-British period is all from natural brine springs, limited to the area of the salt towns of Cheshire (Middlewich and Nantwich) and Droitwich and Upwich in Worcestershire.

Minor salt-making sites have been recorded in Cornwall (Peacock 1969), Isle of Wight, Hampshire and Kent. Iron Age/ Romano-British coastal salt extraction has also been identified close to the Trent/ Ouse confluence in East Yorkshire (D Cranstone *pers comm*).

2.16.1 Prehistoric and Roman

INLAND

Cheshire and Worcestershire

The only mineral salt (as opposed to sea salt) extraction known to have taken place within Britain during the Iron Age was that undertaken at Droitwich in Worcestershire; specifically, the tapping of natural brine springs, and the boiling of brine in pans, the evidence for which is recorded from the archaeological remains uncovered at Droitwich (Woodiwiss 1992) and Upwich (Hurst 1997).

Cheshire was an important centre for salt production in Roman times, and a recent volume of papers entitled: *Brine in Britannia: recent archaeological work on the Roman salt industry in Cheshire* (Nevell & Fielding 2005) is available, it covers aspects of Cheshire's salt archaeology. In Roman times, salt was extracted from brine springs at Middlewich (King Street, Middlewich: Williams & Reid 2008) and boiled in lead pans; which were probably also produced locally.

Cambridge

Palmer (*in* Lane & Coles 2002) in his work on the Fenland of Cambridge identifies Roman turbaries (peat cuttings) either side of the Fen Causeway, and links these to fuel requirements for large-scale Roman salt extraction (sleeching) operations of the estuarine saline silts. The evidence for the saltmaking can be

found in the northern part of the fens in the Upwell district. During excavations by Atkins, the existence of a Roman salting site and associated settlement was established at March. (Atkins 2003)

COASTAL

These sites have been identified mostly on the basis of their briquetage type, any accompanying pottery, and sometimes palaeoenvironmental data. Morris (Lane & Morris 2001) has provided some chronological resolution to this; the earliest identified sites appearing to be Bronze Age in date.

Lincolnshire

General accounts of salt making in the Lincolnshire fens have been provided by Lane and Morris (2001) and Thomas & Fletcher (2001). A fairly intact Late Bronze Age salt extraction site was excavated at Tetney near Cleethorpes in 1993. A fire pit, with briquetage containers (including pan supports), adjacent to the site of a large saltwater pool was excavated by Colin Palmer-Brown of Lindsey Archaeological Services in 1993 (Palmer-Brown 1993).

One of the earliest coastal sites examined was that at Ingoldmells Beach (A Crosby *pers comm*) where well-preserved briquetage containers of Middle Iron Age date were found. Along the same coast, an earlier Iron Age saltern has been excavated at Cow Bit Wash, and inland at Outgang Road, Langtoft and Market Deeping (Lane 2001), Deeping St. James and the Bourne-Morton Canal (Trimble 2001), the Lindsey Coast and Marshland (Kirkham 2001), and at Gold Dyke Bank, Wrangle (Darling & Precious 2001). This important salt-producing area has produced some of the earliest Roman salt extraction sites such as that at Moreton Fen (Trimble 2001). Others have been identified on the Lindsey coast (Kirkham 2001) and at Market Deeping.

Norfolk

One of the more thoroughly examined coastal Roman salt extraction sites discussed in Lane and Morris 2001 is the one at Middleton (Crowson 2001). Other moderately well-studied sites include those at London Lode Farm, Nordelph and Straw Hall Farm at Downham West (Crowson 2001). Some of the large saltern (mound) sites near King's Lynn may also be Romano-British in date (see Hamburg Way, King's Lynn grey report (Timberlake 2007).

Dorset

Iron Age / Roman briquetage and salt extraction sites have been identified within the area of Poole Harbour and Kimmeridge (D Cranstone *pers comm*); at the latter site the Kimmeridge oil shale was used as a fuel for the briquetage pans. Hengistbury Head (an Iron Age

settlement) was also a salt producing site. The briquetage from here suggests that generically this belongs to the Solent group of salt extraction sites (Hampshire coast) which includes Portsmouth and Langstone harbours (D Cranstone *pers comm*).

Hampshire

Iron Age / Romano-British sites have been identified on the basis of their briquetage within the area of Portsmouth/ Langstone/ Chichester harbours. It is possible that many of the sites originally identified by Bradley in the 1960s have since eroded away (D Cranstone *pers comm*)

Kent

Many Iron Age / Romano-British coastal salt production sites are listed in the NMR and local SMR (inf. D Cranstone) and a site was investigated at Scotney in the 1990s (Barber 1998).

Essex

Earlier Bronze Age salterns have been identified at Mucking, and at Fenn Creek dating from the Middle Bronze Age. Some of the earliest of the Roman Red Hills (sleeching and burning sites), such as at West Mersea, appear to have had Iron Age origins (Sealey 1995). Sheepen Road, Colchester is Prehistoric to Romano-British in date (Orr 2006, 7). Several general papers on salting in this county have been published (Gurney 1978; Fawn et al. 1990; Sealey 1995). Romano-British salt extraction sites are to be found at a number of the estuarine coastal locations, typically as 'red hills'. Examples of these can be found at Maldon and on the Blackwater Estuary. Cranstone identified a boundary zone between the North Essex and Thames Estuary Group and the North Kent Group around the Dengie Peninsula.

West Sussex

Evidence of Roman salt production was retrieved during a rescue excavation at Chichester harbour (Bradley 1992). Beckett's Barn near Selsey Bill is a possible prehistoric saltern site associated with burnt stone (D Cranstone *pers comm*).

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**Appendix
Table I**

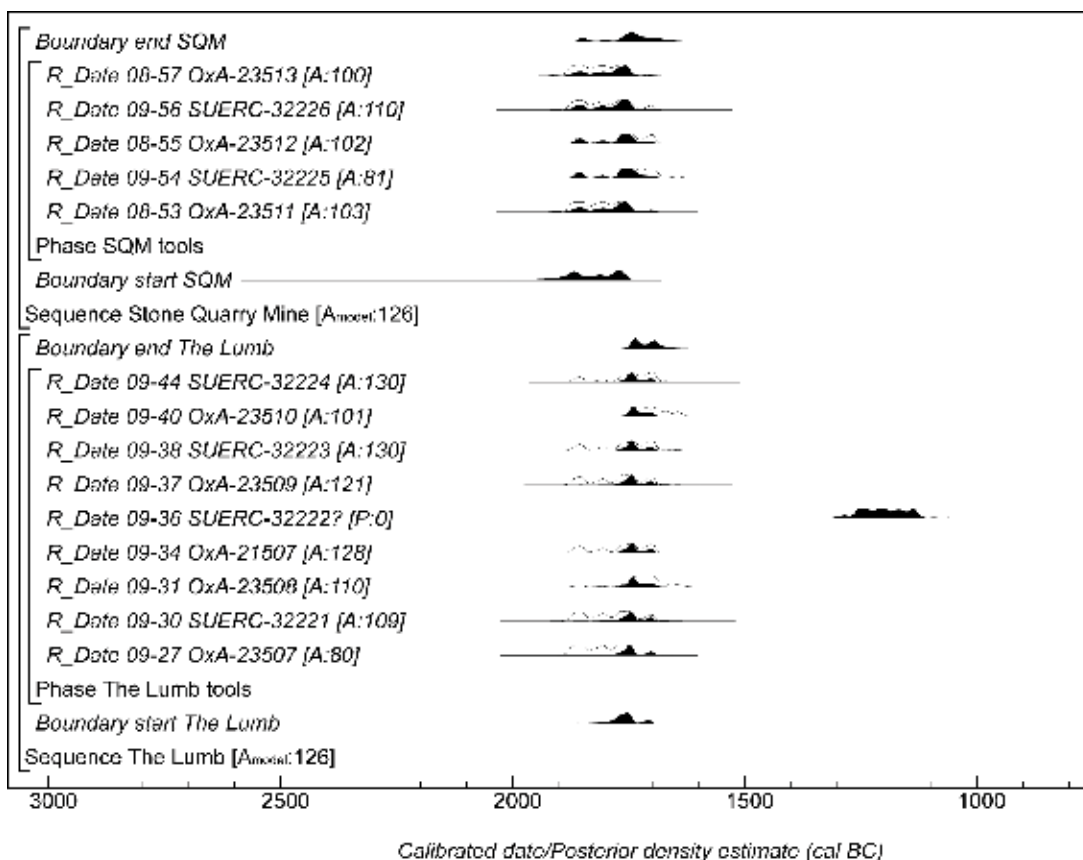
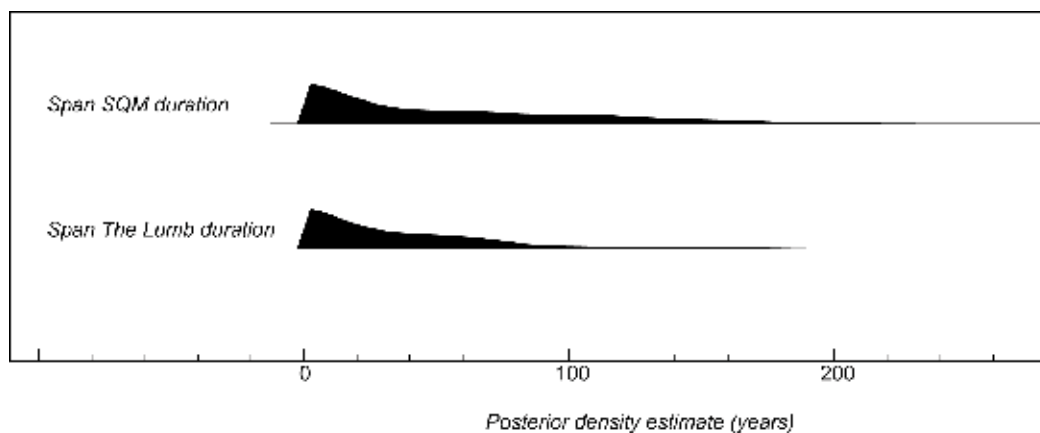


Table 2



3 Bulk Minerals

Ian Thomas

3.1 Introduction

3.1.1 Scope

'Bulk minerals' is a 'catch all' category, which includes all types of rock, sand and gravel. In the industry the term would also usually include 'common clay' (for bricks, tiles etc.) and gypsum. However, these are covered elsewhere in this assessment (Section 6).

Whereas 'rock' is usually applied to material in the ground and 'stone' to the extracted or worked product, in many instances 'stone' is used in both contexts. Geologists may also include soft sediments such as mudrocks (clay, shale, mudstone, special clays) and unconsolidated sand in the term 'rock', but here the

more generally understood usage, of stone as being a relatively resilient material, is adopted.

The term 'bulk minerals' embraces materials used not only for bulk, but also for a wide range of more refined purposes, such as industrial raw materials, high specification construction aggregates, building, sculpting and decorative purposes. The extraction of these commodities represents our oldest organised industry, when stone provided the materials for the first tools, and they still represent the most wide ranging and greatest output of any mineral category. Of the sub-categories, limestones are the most versatile and the most sought after, sometimes dubbed 'the World's most useful rock'. Sand and gravel, although the most

PRODUCT	PERIOD												
	PALAEOLITHIC	MESOLITHIC	NEOLITHIC	BRONZE	IRON	ROMAN	EARLY MEDIEVAL	MEDIEVAL	EARLY MODERN	INDUSTRIAL	VICTORIAN	20th CENTURY	
	-2400	-2400	-700	43	410	1066	1540	1750	1837	1900	2000		
CAVE HABITATION	■												
IMPLEMENTS - FLINT	■	■	■										
IMPLEMENTS - STONE	■	■	■										
LARGE MONUMENTS			■	■									
FIELD WALLS					■	■		■	■	■	■	■	
BUILDING STONE						■	■	■	■	■	■	■	■
LIME - MORTAR						■	■	■	■	■	■	■	■
LIME - AGRICULTURE										■	■	■	■
ABRASIVES					■	■	■	■	■	■	■	■	■
GENERAL AGGREGATES						■	■	■	■	■	■	■	■
"CEMENT"						■	■	■	■	■	■	■	■
METALLURGICAL						?	?	?	■	■	■	■	■
RAIL BALLAST											■	■	■
MINOR CHEMICALS								■	■	■	■	■	■
BULK CHEMICALS										■	■	■	■
GLASS						?	?	?	?	■	■	■	■

Index

- General usage
- High levels of usage
- ? Unsure but probable

Table 3.1 Chronological intensity of usage.

widely occurring commodities, are historically the least reported; sandstone and igneous rock are particularly significant in specific areas; dolomite and slate are much more restricted in occurrence. In England, apart from slate, metamorphic rocks have an extremely limited distribution.

More detail on the various geological types of bulk mineral resources is given in the Geology section below.

Stone often features significantly in county or city museums. For example, the state of the art 'Collection' museum in Lincoln displays stone in the form of flint and stone implements, honestones, metal moulds, sinkers, querns, mortars, millstones, mosaic and the foundations of a building, all without reference to the quarry sources.

Collectively, the archaeological community has extensive data bases and reference collections covering most of these artefacts. Even taken together, these are all niche products accounting for a small proportion of all bulk mineral output. Most of these artefacts have been well-researched, indeed more is known about them than about their sourcing.

3.1.2 Mixed terminologies

Slate, marble and granite

There are a number of minor, but historically very important, categories of rock terms, which can be confusing. To the geologist, slate and marble are both defined as the product of metamorphic processes. General commercial usage in the past is not tied to geological origins, but is determined by the rock properties.

The term 'slate' covered any readily cleavable, rock and, as such, included many sandstones of the Pennines, used locally or in neighbouring cities. In the past these were sometimes called 'grey slates' to distinguish them from metamorphic, blue slates; the term also included limestones in the Jurassic stone belt (e.g. Wychwood, Stonesfield (Oxfordshire) and Collyweston (Northamptonshire): none of these have undergone metamorphism.

Similarly any limestone or dolomite capable of taking and retaining a high surface polish was classed as marble, the best examples being those of the Devonian of South Devon and Purbeck marble from Dorset. Also, the Carboniferous sources such as Hopton Wood and the so-called black 'marbles' of Ashford (Derbyshire), Dentdale (Cumbria), Frosterley (Co. Durham), and Nidderdale (Yorkshire Dales).

Occasionally, various very hard grainy rocks including some robust sandstones (e.g. at Ingleton in the Yorkshire Dales and around Shrewsbury) or basalt (e.g. near Buxton in Derbyshire and at Clee Hill,

Shropshire) were sold widely, and promoted, as 'granite' well into the post-Second World War period.

'Ganister' is another disputed term. In some areas and contexts, it is applied to an aluminous or siliceous clay, whereas elsewhere it refers to a very hard siliceous rock. In both instances ganister was a raw material used for refractory furnace linings.

Aggregates

In some industrial archaeological and historical literature, crushed rock operations are assigned to 'roadstone' production and sometimes differentiated from 'aggregate', which is often confined to the sands and gravels used in concrete and mortar making. This approach reflects common usage up until the 1960s but it was also dominated by practice in the Southeast, where, due to the local geology, sand and gravel represented the bulk of aggregates consumption. Today it is more appropriate to use the term aggregate(s) to cover all crushed rock, and sand and gravel for granular material employed in construction. This would be consistent with government publications. Materials won from natural deposits are now termed 'primary aggregates'; those manufactured, derived as by-products or recycled, are loosely grouped as 'secondary aggregates'. Where appropriate 'roadstone' still has relevance when used generically in respect of aggregates utilised in roads and items such as setts, cobbles, paving, channels, kerbs etc.

Mines, quarries etc.

There is considerable confusion between the terms 'mine' and 'quarry' and this has been evident for many centuries in conventional, legal and even statutory usage. Indeed the application of the two terms has been a matter of High Court contention, particularly in the 19th century, and has rarely if ever been fully resolved, particularly as interpretation changes with location and time.

'Quarry', indicating a place where stone is extracted, first appears in English around the early 15th century (1375-1425 Middle English – 'quarey'). As building stone was almost always won from surface workings initially, quarrying began to be applied more widely to all open, as opposed to underground, operations, irrespective of the commodity extracted, although some purists still seek to limit 'quarries' to stone extraction *per se*, and to include underground workings but this has a long and logical pedigree:

A mine is defined to be certain Foramen, Hole, Hollow place, or a Passage digged in the Earth, from whence Metals or Minerals are by labour raised; for if common Stones only are found (as Marble, Touchstone, Freestone, &c) we call them quarries, and not mines. And where Clays are digged we call them pits. (J Pettus 1670)

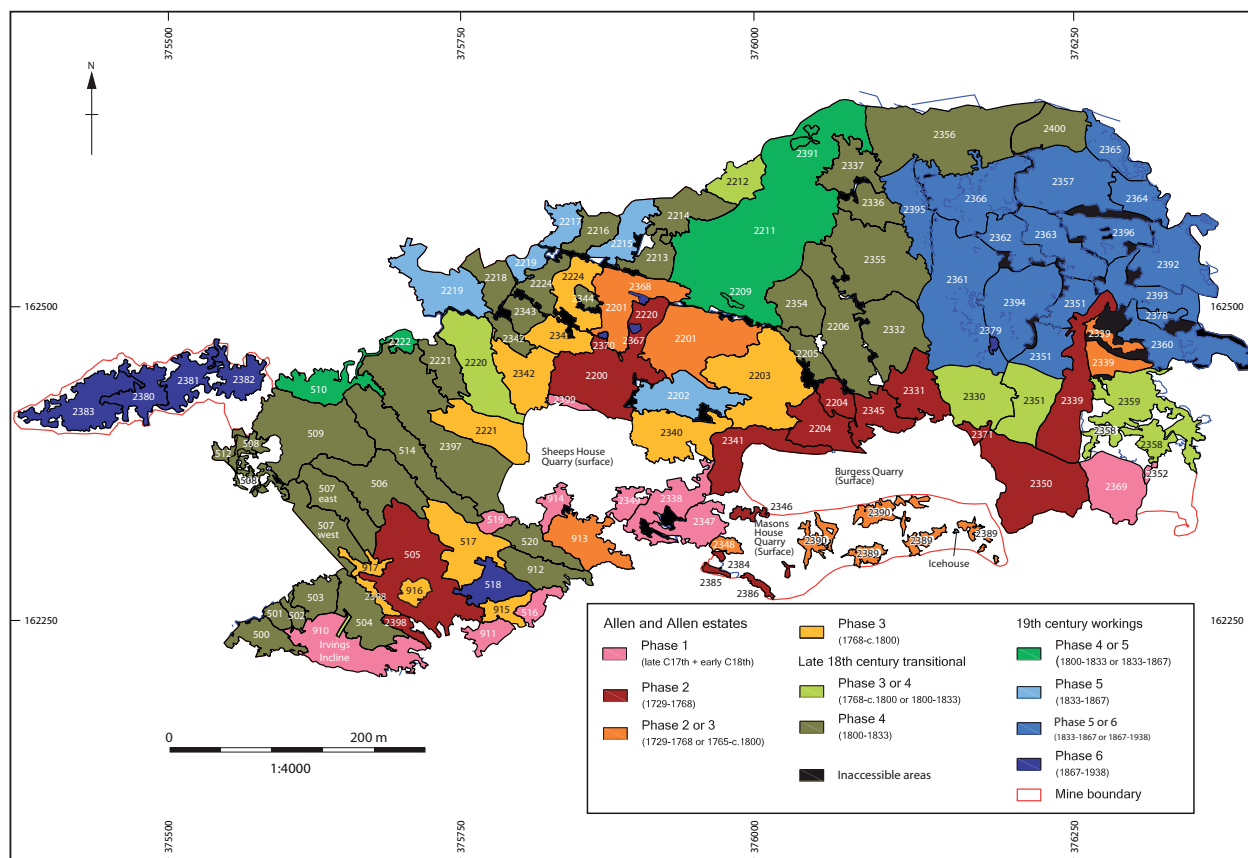


Figure 3.1 Over time, underground extraction has supplied a minute percentage of output but has attracted a very high proportion of research effort. This chronological plan shows operations on Combe Down, Bath prior to infilling to stabilise the surface (underground workings here are known as 'quarries'). © Oxford Archaeology Ltd

In many early documents, certainly up to 1850 and occasionally after that date, the word 'mine' was applied to a deposit, referring to a resource (worked or unworked) of that mineral and not necessary to an operation. It was a natural asset or potential asset. Its usage in the past was probably intended to cover the uncertainty of its scale, value and potential. Less often, the word 'quarry' was assigned to a resource rather than an extractive operation, reflecting to some extent the varying theories or folklore as to how it originated.

In other central and North European languages the English translation of the term used for the equivalent activities, would be 'day working/day mine'.

The origin of the word 'mine' appears to have its roots in Celtic language forms (via Medieval Latin and old French) and first appears in documentation in England in about 1300 AD (1275-1325 AD). One of the early usages of the words 'mine' or 'miners' is associated with the activity of undermining of fortifications, indeed the explosive 'mine' comes from the same background. The general term 'mine' has very widespread, direct linguistic equivalents in much of Europe. By general convention, 'mine' began to be associated more with underground workings.

In older usages, one of the few areas of common ground in definitions is the association of 'quarry' with stone working, whereas 'mine' was generally unrestricted in its reference to mineral type.

The use of the term 'quarry' for almost any type of rock extraction (including ironstone) has increased gradually from the mid-19th century onwards (witness the labelling on most OS large scale maps). Nevertheless, the close linkage between 'quarry' and 'stone' (especially for building) was generally maintained until the 1960s, when 'quarry' began to be applied in the UK on a wide scale to most surface mineral workings. Hitherto, the word 'pit' was generally applied to softer (e.g. clay or shale) and unconsolidated materials (e.g. sand and gravel). The change of usage to 'quarry' for such materials appears to have been spurred by the dislike in some sections of the industry with 'pit' on account of its association with coal mining (originally during periods of industrial unrest in this industry) and the desire for more universally applicable terms. However, historically, 'pit' (and obvious earlier variants, pyt, pytte) was applied to more or less any hole in the ground, and therefore to almost any form of mineral working, stone included. There are two situations where current

conventional usage of the terms 'mine' and 'quarry' are reversed. Since the advent of large scale opencast coal working in 1942, most such operations have been termed mines although they are, in essence, surface activities. The second instance is in respect of some underground building stone operations called 'quarries'. Although this last usage is geographically very limited, traditionally it is applied to perhaps the greatest single concentration of large underground building stone operations, all within a 20 mile radius of Bath. In the case of both these reversals, it would appear that the usage has been applied when initial conventional working of the mineral in question migrated from underground to surface (coal) or vice versa (building stone) and the former terms retained despite the radical change of extractive technique.

Although mines (in the sense of underground operations) had been the subject of specific legislation in England and Wales since at least 1842, quarries were first legally defined as work spaces in the Metalliferous Mines Regulation Act 1872 and the Factories and Workshop Act 1875 as 'any place not being a mine, in which persons work in getting slate, stone, coprolites or other minerals [being] not more than 20 feet deep'. More specific controls over quarrying were not introduced until the 1894 Quarries Act, in which the legal term 'quarry' was applied to surface workings of 20ft or greater depth. Thus numerous shallow operations (including most for sand and gravel), were excluded from statistics or inspection and not recorded until 1938.

Old references to working sites

Some place names (as in some Saxon settlements) provide a hint of stone working in the use of 'stan' as

a prefix and more locally references to hills and holes, hills and hollows etc. The term 'boulder pit' was applied to random workings in West Yorkshire exploiting glacial limestone erratics.

Three other terms to note are delf, delph, and delves (used without discrimination as to surface or underground working). These terms have been revived recently by English Heritage to differentiate small building-stone operations from larger quarries. They come from Old English, *Gedelf*, meaning quarry. These terms usually refer to small workings, often for stone, but also for clay, coal etc, particularly in the northern half of England and some eastern counties. The village of Delph, Saddleworth (where bakestones were extracted from Medieval times to about 1900) is an obvious example. The compound 'standelf' or similar often occurs as a field or area name or as Stonydelph near Tamworth. References to quarry rights become more frequent from 1250. The place or operational names, *greave*, *grave* or similar, were used in the north of England to denote a mine (e.g. *Youlgreave* in Derbyshire and *Stangrave* in Yorkshire (cf. Scandinavia: *gruve*, or German: *Grube*, meaning mine).

3.2 Consumption

The exploitation of bulk minerals is the world's oldest 'industry' and it is still the largest commodity producer, at least in tonnage terms. Its products are used many times a day.

Stone quarrying was by far the most important mining industry in medieval Europe, more important possibly than all the others combined the mining of stone in



Figure 3.2 More intensive and systematic research has probably been conducted into the pre-Roman 'industry' than in respect of the totality of subsequent periods. The lofty activities on the Langdale Pikes, Cumbria served a national demand for stone implements. © Ian Thomas

the middle ages can only be compared to the mining of coal in the nineteenth century and the drilling of oil in the twentieth century.

Jean Gimpel (1977) *The medieval machine: the industrial revolution of the Middle ages.*

The main bulk raw materials mineral 'products' can be grouped (see Stanier 2000, 36) as follows:

Table 3.2 Archaeological coverage of products

Product	Poor	Medium	Good	Consumption
Cave shelters			***	1s tpa
Implements			***	10s tpa
Monuments		**	*	10s tpa
Shaped stone		**	*	100ks - 1ms tpa
Rubble stone	***			100ks tpa
Decorative stone			***	100s tpa
Roofing stone		**	*	1ks tpa
Abrasives			***	1ks tpa
Aggregates	***			100s ms tpa
Industrial stone	*		**	10s ms tpa

3.2.1 Prehistoric and Roman

[As a means of avoiding duplication, stone when employed for use as portable artefacts, tools and weapons during the prehistoric period is dealt with mainly in Section 2, whereas stone used for construction, particularly from the Roman period onwards, is discussed below.]

3.2.2 Neolithic stone monuments

In England, stone structures first became a feature of the landscape during the Neolithic period. These included stone circles and alignments, chambered tombs and standing stones. These first appeared in the fourth millennia BC and continued to be built well into the second. All are well documented in the archaeological record.

3.2.3 Bronze Age to Roman usage

Changes in subsistence strategies and social organisation in the Bronze and Iron Ages resulted in new patterns of stone usage. The introduction of metallurgy generated some additional applications and querns for grinding cereal grains also began to feature as an important product in the archaeological record (see Section 2.15).

Stone buildings and structures

There are many examples of stone being used to construct the base walls of robust round houses and



Figure 3.3 This Bronze age log boat was found near Derby, carrying a cargo of shaped stone blocks possibly destined for building a causeway across the Trent floodplain. © Derby Museum

the boundaries of enclosed settlements and field systems. On Dartmoor over 4000 stone hut circles have been recorded (Butler 1997, 141), and other examples are known on Bodmin Moor and West Penwith in Cornwall. Such houses may date from the early 2nd to the late 1st millennium BC. Elsewhere in England stone round houses are found at Big Moor in the Peak District, and in the Cheviots but appear to be relatively rare outside the Southwest. Chysauster stone village in Cornwall is a Romano-British example of a courtyard style dwelling constructed from stone. Larger stones were used as gateposts for enclosures, and as footings or pads for timber, wattle or cob buildings (a tradition still maintained in vernacular building right up to the early 20th century).

Metallurgical uses

The advent of metal production in the Bronze Age brought a demand for the means to contain and direct heat, (that is, in refractory materials such as furnace linings, channels or casting moulds). These appear to have been derived mainly from local sandstones, sands or clays with a high alumina or silica content (see Section 6, Clays). Fluxes are added to furnace feeds to lower melting points and reduce viscosity of the melt. When fluxes were absent in the host ore and rock, such as Coal Measure ironstones, limestone needed to be introduced as a flux. Honestones (whetstones) were also in demand with the introduction of edged metal tools and weapons.

Grinding with stone

From the Neolithic to the early 20th century AD, stone



Figure 3.4 A ruined 2nd millennium BC (Bronze Age) stone round house at Fernworthy on Dartmoor, Devon. © Phil Newman

has played a major role in grinding processes (Kempe & Harvey 1983). Furthermore, remnant abrasive stones, being portable and resilient, have often provided an important type, if only a volumetrically small tonnage of commonly found artefacts at archaeological sites (see Section 2.14). Fine grained sandstones, hornfels and hard mudstones were deployed as whetstones or honestones (Moore 1978;1983). From the introduction of grain cultivation, a variety of rocks, mainly sandstones and certain igneous rocks, were used as querns. Sandstone and quartzite pebbles were used to process ore at such sites as Alderley Edge and Ecton.

Roman construction

Roman road building demanded stone supplies within the first few years of the occupation, underpinning the construction of 6000 miles (10,000km) of main roads in Britain. Based on averages (6.6m x 0.5m of 'metalling'), these roads imposed an estimated demand of 20 million cubic metres, or 40 million tonnes (author's estimate) of material, mostly derived from resources close to the road (including some recycled iron slags in the Weald - Margary 1965). Another calculation suggested that the streets of Cirencester alone consumed some 150,000 cubic metres of aggregate and that resurfacing was necessary at 15 year intervals (Watcher 1995).

It was in the 2nd century AD that most Roman towns began to have substantial masonry buildings (Pearson 2006). Once the main road building programme was complete, for about 1800 years, block stone (also widely known as dimensional or architectural stone) for construction, dominated the market. In the case of limestone, it was often coupled with the burning of the stone to produce mortar. Although no pre-Roman examples of kilns have been recorded, it is likely that lime was in use during the pre-Roman Iron Age (D Johnson *pers comm*) and was used more widely after the Romans arrived.

Roman buildings made extensive use of stone and

lime render, the former being usually sourced locally for walls and occasionally for roofing (as opposed to clay products). Decorative stone was typically more exotic but not necessarily always imported (Blagg 1990; Pearson 2006).

3.2.4 Medieval consumption

Building, dimension and decorative stone to 1540

Occasionally, stonework shows continuity of use from Roman through Anglo-Saxon times, at places such as Pevensey and Portchester Castles, among others on the 'Saxon Shore', and parts of London and Leicester city walls.

The Anglo-Saxon stone industry was probably initially based around recycling former Roman period material, but by the 10-11th centuries, primary extraction had become well established (Jope 1964). In pre-Norman times, although monasteries and churches were sometimes of stone, domestic and Royal buildings (even palaces) were largely of timber (Jope 1964, 91).

From the 11th and 12th centuries onwards, an increase in the use of stone as a building material is evident. Numerous small churches and most cathedrals were modified over the ensuing five centuries, often altering existing earlier work and distorting our perception of the contribution and extent of the early medieval extractive industry in architectural projects. Cathedrals and abbeys were built, or rebuilt, on a much grander scale. In every county in England many new monastic buildings were founded over the next 200 years. Later, the Dissolution of the monasteries and their estates in the 1540s caused radical changes in the stone industry, as disused monastic buildings became virtual quarries for the successor landowners and local communities.

Ecclesiastical foundations were the main, longstanding players in the medieval industry (Parsons 1990b; Salzman 1957 & 1970; Knoope & Jones 1938; Aston 2000) whereas castles had a significant but generally more localised role as stone consumers. Initially, where stone was employed at prestigious church and castle-building in southern England, it was accomplished by a significant, but not total, dependence upon imports, especially from the Caen and Marquise areas of northern France, supplemented by Kentish Ragstone and Quarr stone. Caen Stone was still being imported into England in 14th century (Glasscock 1976, 173). Frosterley 'marble' from Weardale and Purbeck marble from southern England were both utilised as columns in Durham Cathedral in 1183.

The majority of English parish churches were in existence by 1200 (Donkin 1976, 110), and most were



Figure 3.5 For several centuries after the Romans departed, their buildings became virtual quarries. Depleted Roman lighthouse (right) and adjacent Saxon church (left), Dover Castle. Ian Thomas

probably constructed of local stone from the outset. Where fine stone was available at a slightly greater distance, this was also employed as ashlar for dressings requiring a regular edge, such as quoins and openings (Jope 1964, 114).

In addition to the many castles built in England, numerous Welsh castles were commissioned by Edward I in the latter part of the 13th century, built by substantial numbers of conscripted English skilled workers. The accounts of this episode give a snapshot of the English industry of the time, its scale and distribution, techniques and materials (Colvin 1963). England also became an exporter of stone to Wales, including cream limestone from Dundry, Somerset and red sandstone from Cheshire (Coulson 2005).

Sometimes, stone formed an important component of artillery warfare. In the Iron Age, flint pebbles gathered from Chesil Beach and hoarded at nearby Maiden Castle were used as sling-shot. From Roman until Norman times, stones were used as catapult ordnance, and according to the Mary Rose inventory, were used as canon ammunition. These would be hand trimmed stone balls up to 600lbs, and varied from flint, to hard limestone, basalt etc. Kent was a major source (Salzman 1970, 88).

Although stone may have dominated the skyline of our medieval towns and cities in the form of castles and ecclesiastical buildings, and stone bridges became more common, its use in domestic buildings was less developed. Even in many areas where stone deposits were widely available (e.g. in northern England and Welsh Marches), it was not generally used unless timber was in short supply. Exceptionally therefore it was used; in the West country for example, stone-built longhouses were a tradition from at least the mid 13th century on Dartmoor (Newman 2011, 133). Only when



Figure 3.6 Even where stone was readily available, its post-Roman use was largely confined to churches, bridges and defence; the 12th-century Jew's House at Lincoln is exceptional and probably the oldest still occupied stone house in England. © Ian Thomas

the great prosperity generated by wool fleeces brought affluence to the Jurassic Stone Belt, especially from 12th to 14th centuries, did stone vernacular buildings become more commonplace. Elsewhere, this was not generally the case, indeed the use of stone in houses was sufficiently remarkable to apply the name 'The Stonehouse' to such buildings. In Lincoln for example, the mid 12th century Jew's House was noteworthy as being probably the only 'ordinary' house of stone, for a long period, in the city. Alongside stone for building, there was a complementary increase in demand for lime mortar.

Industrial and other uses to 1540

The uses of bulk minerals for industrial purposes widened gradually from the Norman invasion onwards. This emergent range of applications for limestone, lime and in some cases, sand, included sectors such as leather tanning, glass making, paints, disinfectant (notably used in times of plague), possibly soap boiling and of course metal production. These were precursors to the boom in demand during the Industrial Revolution.

The point of realisation that lime could play a role in increasing crop yields is uncertain but appears to be at the very end of this period. For example, it is generally acknowledged that John Fitzherbert, writing in 1523, was innovative in advocating the use of lime as a soil treatment.

3.2.5 Post-medieval consumption

Building stone

The resurgence of building in the post-medieval period, is sometimes, unhelpfully, known as the Great Rebuilding, a term originally coined by Hoskins (1955). Exactly when it occurred and how it affected different

regions and social classes is contested among scholars (e.g. Brunskill 2006) but essentially a growth in domestic building, including in stone, increased from the 16th century.

Even in the Pennines, where stone was abundant, domestic properties in stone were not the norm until the late 16th or the 17th century. In towns, a series of disastrous fires in the 17th century (in London and Norwich for example) resulted in by-laws prohibiting combustible building materials, which increased the demand for brick and stone.

With the emergence of grand country houses, numerous small quarries were opened (Clifton Taylor 1972, 36) and old sites (often ecclesiastical in origin) were reopened. By 1700, where stone was available it had reputedly become the building material of choice for domestic construction. Once developed, extraction sites continued to be active, often for centuries, in some instances until the 1940s. Stone retained a position as a prestige material, even with the rise of brick; indeed in 'brick' areas stone use for dressings and embellishment was often considered 'socially desirable'. Conversely, in some stone areas, it was brick that was sometimes imported as an indicator of status.

The extravagance embodied in houses at Wollaton (Nottinghamshire), Longleat (Wiltshire), Chatsworth (Derbyshire), Burghley (Lincolnshire), Hardwick (Derbyshire) began in the mid to late 16th century, and is seen at hundreds of lesser houses.

Through the Renaissance into the Neoclassical

period, the trend continued. During the latter, stucco rendering on brick or inferior stone work, using patent cements, often masqueraded as stone in urban and 'stoneless' areas.

In the 18th century some stones gained national, rather than purely local or regional, significance; foremost among these were the Portland and Bath limestones, followed in the early 19th century by some of the more notable Pennine sandstones (Hudson 1971; Hawkins 2011; Hackman 2014).

The growth of urban areas and commerce in 19th-century England brought with it an unprecedented rise in the demand for stone, especially outside the Southeast. Even in the 'brick zones', stone was widely employed as dressings in many very mundane buildings (Lott 2008). The Great Exhibition of 1851 promoted a broader awareness of stone products and their availability.

The interruptions of two World Wars and the burgeoning use of concrete, especially as a structural element such as over openings, led to a hiatus in demand for building stone in England. After a small post-War resurgence to reinstate bomb damaged buildings, what appeared to be terminal decline set in. However, from the low point, at around 1970, a growing awareness of conservation and design (coupled with the introduction of new machinery) has generated a steady increase in demand, especially for prestigious projects.

One of the volumetrically largest, most extensive and enduring uses of stone, was in building field walls.

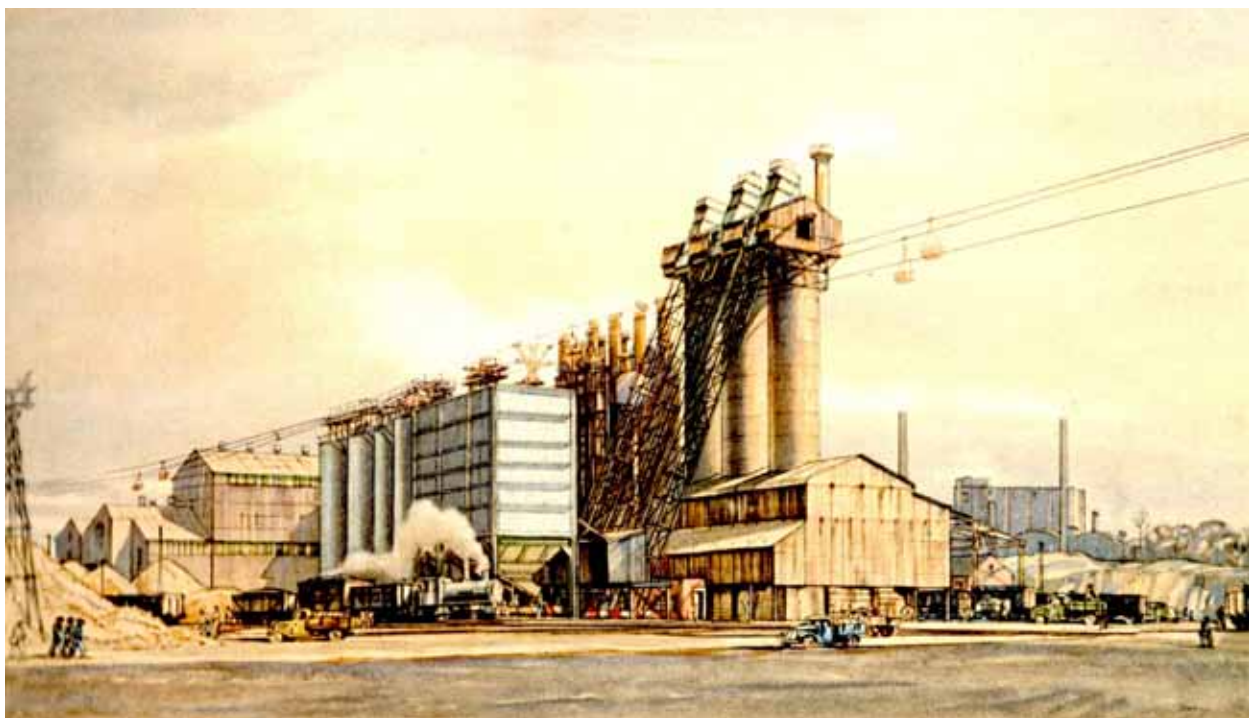


Figure 3.7 This large complex at Steeley, Worksop, Nottinghamshire pictured in the 1940s, was a world leader in dolomite technology. Ian Thomas collection, Artist: Henry Rushbury RA.

Not only were these designed to delineate boundaries and retain stock, they often served as mechanisms for field clearance of stones. Although some field boundaries incorporating stone date back to the 2nd millennium BC, such as the Dartmoor reaves (Newman 2011, 72-82), and have been rebuilt many times, other walls still in use have medieval origins, while most date from the enclosure of the 18th and early 19th centuries (Rainsford Hannay 1999).

A minor, but important, building use of stone was in roofing materials. The two main categories are metamorphic and 'stone' slates, the latter being fissile limestones and sandstones. Stone slates began to replace thatch in the late medieval period (Hughes 2003) and became common with the 'great rebuilding' of the 16th -17th centuries, but in turn began to be superseded by metamorphic slates, especially during Victorian urban expansion. In 1831, the abolition of taxes on slate carried by sea, gave Welsh and Cumbrian material a further boost.

Industrial uses (post 1750)

The last quarter of the 18th century saw a plethora of breakthroughs in science and technology, which increased the demand for stone. In the 19th century, the period from 1820 to 1875 was one of considerable enterprise and invention, leading to expansion of production, especially of high purity limestone for industrial purposes. Many of these developments set a trend, the impact of which was only fully realised after 1900.

Chemical-based uses

The foremost consumer of chemical grade limestone was the Leblanc process for producing alkalis and other chemicals. It relied upon limestone, salt, coal and iron pyrites. It was developed in the 1760s in France, to solve the longstanding problem of supply (i.e. either as soda ash or sodium carbonate (Na_2CO_3), which was then derived from unreliable production of the natural material 'natron' or the equally uncertain alternative potash, extracted from woodash). However, in England the first works did not become established until 1822.

Flat glass production was boosted by the abolition of the window tax in 1851, and innovations by the Chance Brothers, which in turn increased demand for the ingredients, soda ash, silica sand and limestone. Soda ash also went into 'modern' soaps and hundreds of other products. Bleach (calcium hypochlorite) created another major market for lime.

The Solvay Process, introduced to Britain in 1874, for soda ash manufacture, also required pure limestone and salt. By the 1900s it was superseding Leblanc and continues as a major force today. It is far more efficient and results in significantly less pollution.

The sugar refining process established in the 15th century continues to require limestone (lime), but at much reduced tonnages than in the past.

Alongside these major consumers were hundreds of chemically related applications, particularly for lime, limestone and to a lesser extent, dolomite and silica sand.

Metallurgical uses

Limestone (and after 1880, dolomite-see *below*) was a vital ingredient of metal production during the industrial revolution and is to the present day, in refractory linings and fluxes. The bulk has been consumed in iron making blast furnaces but also it is used in steel production. Lesser volumes have been employed in refining non-ferrous metals.

Lime, or limestone, was used as an iron-making flux but it is difficult to locate early records verifying its use. A smelter at Dudley in the West Midlands appears to be an exception from 1693. By 1745, industrial scale quarrying for flux was underway (Powell 1999).

Iron and volume steel making began to increase in the later 19th century. The development of processes patented by Bessemer in 1856 and Siemens in 1862, offered improved steelmaking in bulk. However, initially their fireclay or silica brick furnace linings could not handle the plentiful, but low grade, UK ores as these are typically high in phosphorous or sulphur. In 1879, Gilchrist and Thomas solved this problem by introducing chemically 'basic' furnaces. These were lined with hard-burned dolomite bricks (trade name 'Doloma') requiring high purity dolomite. Similar linings are still used in cement and lime kilns.

Electric arc furnaces (mainly for melting scrap or producing alloys) became a small but important sub-sector from the First World War, and usually employed 'basic' linings and fluxes. Other furnaces, heat regenerators, gas retorts and coking plants still used silica brick refractories produced from silica rock or silica sand. However, when modern oxygen converters replaced open hearth furnaces from 1960, and natural gas replaced coal gas, silica rock extraction almost ceased. Limestone in blast furnaces, and lime or dolomitic lime continue to be used as fluxes in other furnaces. Special sands were also employed in foundry casting moulds, channels and pig beds for blast furnaces. Traditionally, these were naturally bonded, but increasingly from the 1960s, purer silica sands have been bound synthetically.

Other limes, cements and concrete

Lime was used extensively as a mortar and a render in buildings, as whitewash, or as a basis for paint and in tanning leather. Lime was effectively the only widely available disinfectant – most notably used in times of plague. By the end of the 16th century, liming and

marling to improve crop yields was becoming common practice in the more advanced agricultural areas. A related, important use of lime in the later-18th and earlier-19th centuries was as a defoliant, spread in quantity to remove acid moorland vegetation in advance of reseeding, at a time when many upland commons were being enclosed.

Sand was used primarily in building mortars; much smaller volumes were applied in glass making, scouring metal, dusting floors, brickmaking etc. It was also important in foundry moulding notably for canons and bell-making.

Roman builders used a form of lime-based 'concrete' which incorporated material (volcanic ash, brick dust, crushed pottery) having 'pozzolanic' characteristics. Apart from resilience, it had hydraulic properties, i.e. it was capable of setting under water. Attempts were made to replicate this technique as early as the 16th century by importing volcanic ash ('trass') to England from the Rhine valley.

Cement in the modern sense (i.e. Portland cement) is now one of the World's three or four key construction materials. Although distinctly different in many respects from lime mortar, the evolution from the former material to the latter can be traced from about 1750. Milestones included Smeaton's work on hydraulic limes (1756), Parker's Roman Cement (1796), Aspdin's Portland Cement patent (1824), and Johnson's improvements to it (1850-70s), leading to a material recognisable as Portland cement. By the end of the Second World War, no fewer than 150 sites in Britain had produced Portland cement, served by some of the largest quarries in the country (Francis 1977; Butler 1913; Stanley 1979; Cement Kilns Website¹). Output doubled between 1890 and 1900 to 2 million tons and increased to about 3 million tons in 1910. Having fluctuated thereafter up to 1945, when UK cement production was 4 million tons per annum, it rose to a peak of almost 20 million tons in 1973. Since then, the disbanding of restrictive price agreements and large scale imports, have rationalised capacity overall to little more than half the 1973 level.

From the outset, the main application for Portland cement has been in concrete, and in smaller volumes as building mortar. By 1945, cement had very largely replaced lime in mortars, output of which slumped, but agricultural subsidies maintained lime output at those kilns which had survived wartime anti-flare restrictions. However, beginning with conservation and restoration works, from the 1990s there has been a wider but very gradual return to lime, in place of cement, on grounds of sustainability. Furthermore, in the last 30 years, greater awareness of pollution control needs has promoted new, large scale uses of limestone, such as

in power station flue gas desulphurisation, neutralisation of liquid acidic and other wastes. In agriculture, farmers now generally favour the slower release offered by ground limestone over the more traditional lime.

Aggregates

Between 1756 and 1836, the development of more than 1000 Turnpike Trusts resulted in 23,000 miles of new or improved road in the UK with Telford and Macadam taking a technical lead. Empowering acts often provided for securing stone en-route, effectively from borrow pits.

Meanwhile, in the cities, the increase in traffic resulted in the first experiments with tarred gravel (in Nottingham in 1840) and by the late 1870s, widespread use of asphalt (in place of unbound gravel, granite sets or wood block). The use of tarred macadam (using graded stone) increased significantly following Hooley's patent for 'Tarmac' in 1902 (although initially utilising slag), so that, by 1930, tar coating plants were commonplace (Earl 1971, 1974; Ritchie 1999).

In the interwar and post-Second World War periods, house building priorities boosted the demand for concrete and hence for sand and gravel. The late 1950s through to the 1980s saw uncertainty in the industry, reflecting economic cycles. Overall UK aggregates output quadrupled in the 25 years after c.1950, peaking first in 1973, then in 1989 at c.300 million tons per annum, since when it has fallen back by a third in the 2000s and recently, to half that level.

Motorway construction not only generated direct demand, but the resulting improved transport network influenced the pattern of sourcing and distribution. Rock production accounted for most of the new growth, whereas sand and gravel use declined slowly. In the last two decades, road safety considerations have focussed attention on rock sources offering a high slip resistance and a good abrasion value.

Demand for crushed stone used as rail ballast has fluctuated in response to rail improvements and closures. Since the Second World War, increasingly stringent changes in specifications and higher train speeds, frequencies and loads, have reduced quarry supply sources to a handful of sites, such as Cliffe Hill, Leicestershire and Meldon in Devon which specialise in this usage, although much ballast is imported from Wales and Scotland.

'Heroic' Victorian construction projects, frequently demanded considerable quantities of reliable stone over very reduced periods. Public Health Acts stipulated clean water supplies in the last quarter of the 19th century resulting in numerous large scale masonry dams. In the southern Pennines/Peak District alone, there are 50 reservoirs, usually dating from before 1914. Most of these massive schemes were dependent upon dedicated



Figure 3.8 Both banks of the lower Thames and the Medway tributary hosted much of the World's embryo cement industry and led UK production for a century. Almost nothing remains and very little more has been recorded. Burnham Works, Medway, Kent. © APCM

borrow pits (the Upper Derwent and Longdendale Dams in the Peak District and Thirlmere in the Lake District, being prime examples). An important but related minor use of special sands is in water filtration and effluent treatment, and lime is used in a similar context.

Grinding with stone

Over the centuries, millstones have had a range of forms. Cereal grains were traditionally the main milled product, but other commodities such as mineral ores, pigments, pottery ingredients and a wide range of vegetable products were also processed (Tucker 1977, 1987; Hockensmith & Ward 2007).

The fashion for white bread brought about the first notable change, with imported composite French burr



Figure 3.9 Built in 1879, Bardon Quarry crusher mill (here c.1910) Leicestershire. Although probably the UK's largest existing 19th-century quarry structure, it was unprotected and under threat at the time of writing. © NSC collection

(siliceous) stones in the 18th century replacing the, by then, dominant Peak stones. The latter continued to be employed for coarse grains and provender. In most areas, the downturn in millstone demand appears to have been almost total, apart from those areas where the stone was such that it could be more or less matched by an increased requirement for grindstones used in edge tool making. In turn, the demise of the edge tool grinding market came mainly after the introduction of synthetic grinding wheels at around 1900. However, some quarries diverted efforts to making pulp stones for the worldwide paper industry. The intervention of two world wars disrupted that trade, which, by the 1950's, was overtaken by the use of stainless steel scarifiers. (Tucker 1987; Thomas 1997).

Minor uses such as honestones, sharpening slips, grinding media continued into the 20th century but, apart from very specialist processes, have either ceased or use imported materials. Chert was used until the mid-20th century in grinding calcined flint for the pottery industry, and latterly, for chicken grit and Davie blocks. Distantly related, stone (mainly sandstone but occasionally granite) was used in cider making (as pound stones and edge runners) and cheese presses (as weights) or as rollers (for paths and grassed areas), measuring weights, etc.

Military uses

Defence works in anticipation of a Napoleonic or later invasion led to a large demand for stone along the South Coast. Two of the most significant projects were Plymouth Breakwater (1 mile long consuming c.4.5 million tonnes of limestone from Oreston Quarry



Figure 3.10 Abrasives have attracted a significant proportion of archaeological research. These abandoned stones were destined for pulping timber in paper making but are frequently mistaken for mill- or grindstones. Bolehill Quarry, Grindleford, Derbyshire. © Ian Thomas

near Plymstock 1812-14) and the Portland Breakwaters (using prisoners working c.6 million tonnes of Portland stone between 1849 and 1872), as well as dozens of defensive works, mainly coastal forts and notably 'Martello' towers in the early 19th century.

The Second World War effort required considerable quantities of stone and gravel used as aggregates, not only to construct fortifications, as in previous conflicts, but also on a massive scale as airfields and the Mulberry Ports (for D-Day invasion). This demand continued well into the Cold War period, for nuclear bunkers, and as runways were strengthened to accommodate heavier bombers. Most of the material was sourced from local one off 'borrow-pits'.

One niche market was the use of flint as an ignition component in firearms, this being a speciality of Thetford, (Norfolk) and Brandon (Suffolk) (Mason 1978).

3.3 Development of the modern industry structure

Just as the Saxons found themselves with a ready supply of recycled stone from Roman buildings, the new landowners were able to tap the resources of 'inherited' ecclesiastical estates, in the form of quarries as well as buildings, following the Dissolution. Landed classes were therefore the main players in much of the countryside during the first century of this period.

The Enclosure Acts between 1750 and 1860 often made provision for parish quarries in which parishioners frequently had rights to work such resources, but solely for their own purposes within the parish. Workhouses, introduced under the early 19th-century Poor Laws, were often a part of the system, receiving lump stone from the quarry to be broken down manually by the

inmates, in return for their keep. Similarly, the prison service utilised quarries as a means of hard labour, Dartmoor and Portland being the best known examples.

Contemporary turnpike trusts often acquired rights to work materials for the upkeep of roads, some of which (as with some parish quarries) came under local authority control by 1850, when responsibility for highway maintenance passed into the hands of 15,000 parish and other councils. By these routes, almost every parish had access to its 'own' quarry or gravel pit, usually operating manually and intermittently. Road administration was rationalised from 1882 onwards, but even then, 1800 authorities were responsible for road upkeep, and many of these bodies had multiple quarry operations. Slightly more organised quarrying (often leasing parish or estate interests), being clearly commercial operations, were initiated by individuals or as family run partnerships during the first thirty years of the 20th century.

In the mid/late 1920s, recession hit. The economic pressures of the 1930s led to closures (particularly of sandstone units) with the survivors at local level continuing on an intermittent basis, displaying a gradual switch from, for example, lime burning or building stone to aggregates serving very local markets. Between about 1935 and the mid-1950s, most undertakings began to be managed by registered companies, but were operated by the same people, usually taking their names from the quarry itself, the family or locality.

Alongside these developments, those in the aggregates sector with access to capital, embarked on a series of mergers, firstly at a regional scale then, especially around 1934/5, at regional, (the Southwest; Welsh Borders; Derbyshire) then inter-regional or national level. These changes laid the foundations for today's nationally dominant company groups. Severe rationalisation of production and a long-term trend concentrating on even fewer, larger units ensued. The local highway authorities, hitherto significant players in many areas, mostly pulled out of production around 1930.

By the mid-1950s aggregates dominated output. The 1960s-70s motorway construction programme led to a spate of take-overs, increasing further the dominance of major regional and national producers. Until that point there was a divide between rock producers (concentrating on road aggregates), sand and gravel companies (focussed upon concrete) and slag processors. The mergers brought these three sectors together. The following three decades witnessed the absorption of almost all regional concerns by the majors with, in the main, only specialist producers (of industrial stone/sand or building stone) outside these groups.

At the same time, British companies took over large

parts of the aggregates industry in Europe and North America. However, from the late 1990s, European and, in one instance, Mexican interests acquired most of the UK majors (accounting for over 75% of output). Almost two decades of growth continued until 2008, since when the decline has been unprecedented (Earle 1971, 1974; Thomas 2014).

From the early-19th century onwards, in parallel with the general market, a number of the larger quarries were operated captively by concerns producing for the particular needs of the parent body. Foremost in this category were the iron, canal and railway companies, especially in the Midlands. In the adverse economic conditions of the last quarter of that century, groups of suppliers banded together to maintain prices initially by trade agreements then, in the 1890s, by merger. The larger chemical companies retaliated by acquiring some of the merged groups especially just after the First World War (Peak District; Yorkshire Dales). With growing sophistication and regulation of quarrying practice, coupled with the hike in aggregates demand from the 1960s onwards, many of the captive quarries were divested, succumbing to bids from the major groups. However, with one or two notable exceptions, until about the 1990s, cement producers have usually quarried materials exclusively for their own plants (Francis 1977; Cement Kilns Website¹).

The building stone industry has tended to operate outside these arrangements with combinations in hard times (e.g. 1890s and 1930s) emerging in the granite (Cornwall), limestone (Portland; Bath) and sandstone (Forest of Dean) industries (Hudson 1971; Stanier 1999). Only in the 1970s and 80s did other major quarry concerns intervene, but then rapidly disposed of these acquisitions, in most cases a decade or so later.

Also outside these groupings, slate extraction in England has been carried out independently and specialist dolomite production was for much of the 20th century largely the prerogative, directly or through agreements, of a single concern. Many companies have produced accounts of their historical development, usually to mark key anniversaries. These vary considerably in content and presentation and

in their relevance to the present exercise. Examples include those for Tarmac (Ritchie 1999) Readymix Concrete, now CEMEX (Cassell 1986), McAlpine (Gray 1987) Bath & Portland (Hudson 1971), Blue Circle (Pugh 1988), Steetley (Wilson 1947; Anon 1985).

3.4 Locality

Three factors are vital determinants in the location of bulk mineral extraction, namely resources, transport, and markets. Bulk minerals are relatively low cost, comparatively plentiful, high volume commodities in which logistics plays a critical role.

Their working is dependent upon the properties of raw resources in the ground. Therefore, specific groups of commodities are often now closely concentrated in particular parts of England. With less demanding specifications, and poorer transport links, consumers in the past were more tolerant so the extraction was far more widely distributed than at present.

Source: British Geological Survey – ‘Britpits’ – largely derived from Ordnance Survey maps as at February 2013

The resources of bulk minerals are described in greater detail below and the consumption in Section 3.2.

3.4.1 Overview

Sand and gravel have been exploited in almost every part of England.

The Home Counties have led in the production of sand and gravel, initially from Middlesex, but since the Second World War, its place has been taken variously by Kent, Surrey, Essex and Hertfordshire. Beyond the Southeast, the Trent Valley in Staffordshire and Nottinghamshire are key sources.

Extraction of **limestone** (including chalk and dolomite), especially for lime production, has occurred in every English (1974) county. Derbyshire has been the largest producer of limestone since records were first kept (1895), with the exception of a few years in the later 20th century when it was eclipsed by Somerset.

Table 3.3 Archaeological coverage by rock type and area

Commodity	Poor	Medium	Good
Limestone	Most other areas		York Dales/ S Cumbria
Dolomite	All		
Sandstone	Most areas		
Igneous rock			Southwest England
Sand/Gravel	Most other areas	Trent	All counties
Slate		Parts of Cumbria/Cornwall	

Indeed, Derbyshire has probably led in quarrying high purity stone since the 17th century. Co. Durham, Yorkshire and Shropshire have all played important historic roles.

Chalk has mainly been quarried in Kent and Essex, with Humberside also being important.

Production of high specification **dolomite** has come from Permian rocks and is now confined to two quarries in Derbyshire and Co. Durham respectively.

Sandstone working has been largely confined to the west and north. Yorkshire (especially west and south) and Lancashire, have accounted for the greatest sandstone output.

Igneous rock production, is even more restricted; Leicestershire now contributes by far the largest output but, formerly, Cornwall was a major supplier.

Slate (metamorphic) in England has almost all come from sources in Cumbria (Furness), Cornwall, Devon and Leicestershire.

3.4.2 Neolithic and other prehistoric stone monuments

Hundreds of prehistoric monuments are found in England, particularly in Cumbria, the Peak District, Devon and Cornwall (Burl 1976; 1995). In many instances, the stone was almost certainly won on or near the site, where the availability of suitable large flat blocks may even have sometimes been a locational determinant. Burl (1995, 18) indicates that almost all stones used at stone circles were gathered from within a 1-2 mile (2-4km) radius of the site. The so-called Preseli bluestones of Stonehenge are often quoted as being a notable exception, having originated almost c.300km away, but their mode of delivery to the site is contentious and it is still under debate whether human effort or glacial transport into the region was responsible for their provenance (John 2010; Burl 2007).

3.4.3 Building stone – Roman to 20th century

To avoid duplication with other sections, the following only touches upon selected examples to illustrate particular aspects.

In very general terms, the winning of stone for vernacular buildings was strongly associated, initially in Roman times and then from the late-medieval period onwards, with the so-called Jurassic Stone Belt, which runs from Dorset to Yorkshire. The uniform use of local stone is often regarded as the crowning feature of Cotswold or Rutland villages (Moriarty 1989). Later, the Namurian (Millstone Grit) and Westphalian (Coal Measures) stone of the Pennines and adjacent areas, the



Figure 3.11 Stone represents the World's oldest industry, long pre-dating agriculture. Castlerigg Stone Circle, Cumbria of the late Neolithic is a relatively recent example of stone use. © Phil Newman

Carboniferous Limestone of the Pennines/Peak District, and the granites of the Southwest peninsula, were embraced for stone building, where, hitherto, often a parish's churches and bridges were the only stone-built structures. The softer Permo-Triassic sandstones of the Midlands followed a similar course.

However, material for more prestigious projects, including castles and important ecclesiastical works, especially in the south and east, was often heavily dependent upon access by water transport. So sources were often controlled by the Crown, the Church or colleges, and played a semi-national role (Salzman 1957 & 1970; Knoope & Jones 1938, 1967). These include sources on the south coast (Purbeck, Portland and Isle of Wight) and those in the 'Stone Belt' (Stamford, Barnack, Lincoln via Fenland waterways or Fosdyke, or Tadcaster in the Permian, via the Ouse). Ecclesiastical/monastic stone building occurred throughout England; for example the construction of the Cistercian, Vale Royal Abbey in Cheshire consumed 40,000 cartloads of stone between 1278 and 1281 (Hignett 1935). Huddleston, Rievaulx, Thevesdale and Roche, all in Yorkshire, all had active quarries for relatively local buildings in c.1400. But some stone was moved over difficult terrain; Reigate stone was a major source for London 39 km away; Chilmark in Wiltshire supplied Salisbury Cathedral 28km distant (Sowan 2002); Southwell Minister in Nottinghamshire was granted free passage of stone through Sherwood Forest in 1337, but it had already been worked in the Mansfield area, 25km away, for over two centuries for the same purpose (Thomas 2006).

From the mid to late 16th century, many grander and hundreds of lesser houses, were largely built of stone won from their own or neighbouring estates; for example, Blenheim in Oxfordshire was supplied by a number of local quarries (Clifton-Taylor 1972; Arkell 1948). Chatsworth in Derbyshire drew stone (including decorative materials) from half a dozen quarries, mostly

within a mile of the house (Thomas & Cooper 2008). Indeed a survey of 155 Derbyshire country seats (mainly c.17th to early 20th century), noted that, with only one exception, all the predominantly stone-built houses were found to have drawn the bulk of their materials from within 5km (Craven & Stanley 1982; Alexander 1995).

Stones, which in today's terms are seen as very unpromising on account of their poor weathering characteristics, were utilised for building in the past, including the harder chalks of Beer in Devon, Totternhoe in Bedfordshire, Guildford in Surrey, and the East Riding of Yorkshire. The Permo-Triassic sandstones of many Midlands sites such as Hopwas in Staffordshire, or Weston on Trent in Derbyshire, and Carrstone in Norfolk, were all used widely for building, in some instances until c.1900. However, in some cases they were applied to less exposed or interior work (Sowan 2002; Yates et al. 2006-7; Allen 2004). Grinshill in Shropshire, Hollington in Staffordshire, and Lazonby and St Bees in Cumbria are modern exceptions, as these Permo-Triassic sandstones are robust and still worked. In those parts of the country, where resilient stone is scarce, notably in the Southeast, quarriers have resorted to following more reliable beds underground (Sowan 2002) or to importing stone (Tatton Brown 1990).

Portland stone is probably the only truly 'national' (indeed 'international') player (Hughes et al. 2011). After a decline in the 16th century, as cited by a Royal Commission in the 1580s, the fortunes of Portland stone were revived when Inigo Jones utilised it for the Banqueting Hall at Whitehall in 1619-22, followed 150 years later by Wren and the massive rebuilding programme after London's Great Fire (Hudson 1971). From then on it became the stone of choice, not only in London but in many other cities, notably Dublin and New York, as exemplified in the United Nations Building, as well as for in the headstones of thousands of war graves across the World.

The use of granite as a building material in Devon and Cornwall had focussed on 'moorstone' (i.e. detached) sources, from the prehistoric to post-medieval period. Quarrying techniques developed from about 1800, after which a granite 'industry' developed. Valued for its ability to absorb compression and for its resistance to weathering, it was used in prestigious projects such as New London Bridge, various dockyards and public buildings in the capital and elsewhere (Stanier 1999).

In terms of roofing materials 'stone' slates, predominated for vernacular buildings in the Jurassic stone belt between Bath and Stamford from the 14th century. Further North (and rather later) sandstones played the same role in the Pennines, where they were



Figure 3.12 Archaeological research into quarrying is probably unique in its ability to contribute to other conservation needs. Future controlled extraction may need to be factored-in. Restoration surveys at Crowland Abbey in the Fens indicated usage of seven stone types. © Ian Thomas

known as grey slates. From the 1830s, metamorphic slates became universal in urban areas. Imported Welsh stone swamped the use of Cumbrian and Southwestern material, which, apart from very localised usage, showed little obvious regional pattern.

Lott (2008) provides a detailed review of the growing Victorian building stone industry's relationship to transport developments and markets.

Large construction projects, from the late 18th century to the present day, have demanded considerable quantities of reliable stone over very reduced periods. This has been mainly derived from dedicated 'borrow pits' (i.e. quarry sites where materials have been extracted for use at locations elsewhere), the precise location of which is largely unrecorded.

3.4.4 Aggregates

Aggregates have been won throughout England, the low unit price compared with transport costs favouring local sourcing. However, in English markets since the Second World War there has been a shift in emphasis from peripheral, and especially coastal, rock sites – notably in the Southwest but also in Wales – and from sand and gravel in general, towards multi-million tonne operations known as super-quarries in North

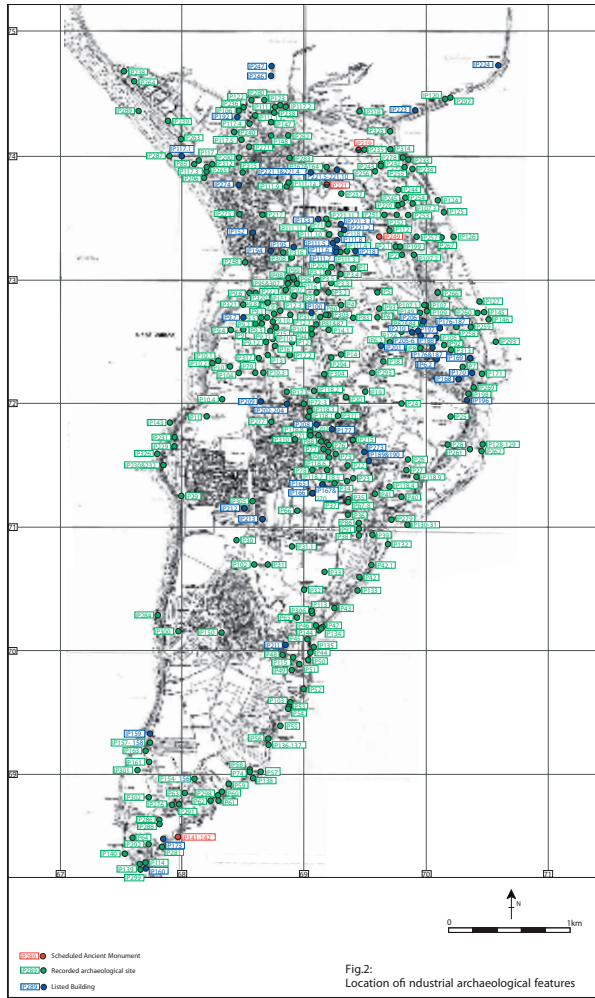


Fig.2: Location of industrial archaeological features

Figure 3.13 Portland is one of the most intensively quarried areas in the country. Stanier and Cox identified about 400 post-1750 sites of industrial archaeological interest [dots on map]. Most related to stone, only a small proportion of which had been previously recognised, let alone protected. © Stanier and Cox

Derbyshire, Charnwood in Leicestershire and East Mendip in Somerset. Much of this was foreseen in the Verney Report in the mid-1970s (IA Thomas 2008). The larger sand and gravel units are almost all in the river valleys, notably the Thames and Trent, the extensive Triassic sandstone quarries of the North Midlands being an exception. Special sands for glassmaking are mainly extracted in South Lancashire, Cheshire, Surrey and Norfolk, and for moulding in Nottinghamshire and Worcestershire. Bedfordshire provides special sands for testing and filtration.

Until about 1900 most aggregates were extracted on the then urban fringes or along river banks, most of which have been overtaken by urban expansion and long forgotten; though evidence of extraction may sometimes be encountered in pre-development excavations.

3.4.5 Lime, cement and concrete

For practical reasons relating to the reactivity of lime with moisture, lime kilns tended to be located close to the point of use (for mortars, tanning etc.) on the edge of towns or along transport routes. With the added recognition of the role of lime in arable farming in the 16th century, even small limestone outcrops were quarried and the lime industry was already regarded as posing pollution issues in medieval times. In some cases, as with the Peak Forest to Buxton limestone area, extensive lime burning took place. Here, 'industrial' production of lime started in the 17th century and commercial output steadily increased with the introduction of tramway, canal and railway infrastructure from the late-18th century onwards. Where they were based on outcrops, kilns were usually sited at the edge of the deposit most accessible to the market and linked by rail or waterway. Elsewhere, marling left behind tell-tale evidence in the form of water-filled pits ('meers') in areas such as the Cheshire Plain and East Anglia (Prince 1964; Glasscock 1976, 216).

Lime production has seen great advances in burning technology (see Section 3.7.11) so that over the last 150 years it has been transformed from a farmer-based industry in areas with local limestone, located at hundreds of sites, to a highly controlled, high investment sector, which in England is now confined largely to four Peak District operations and single sites at Cheddar in Somerset, Shap in Cumbria and Melton Ross in Lincolnshire.

Smeaton's original investigations in 1756 into hydraulic limes, with a focus on the muddy Liassic limestones, represented a precursor to Portland cement making and, like cement, being dependant on a similar clay-rich limestone mix. Barrow on Soar in Leicestershire, Watchet in Somerset, and Rugby in Warwickshire were at that time, the key sources and became early cement producers with the last continuing to the present day. The clay-rich Lower and Middle Chalk was utilised for hydraulic limes, especially in Bedfordshire and North Surrey (Sowan 2002).

The switch to the Southeast came in the later 18th century with the use of lime-rich ('septarian') nodules, gathered on the shores of the Thames Estuary to make patent cements. This was succeeded by an alternative process, blending chalk and clay (see Section 3.7.11), which in turn further stimulated the establishment of numerous Thameside and Medway-based cement operations (Eve & Stead 1999; Francis 1977).

For probably a century up until the 1970s, the Thames Estuary (with Medway) accounted for the greatest proportion of the national cement output (over 75% before the First World War). Humberside was the other significant producer. The fuel crisis in the early

1970s resulted in a change of process which favoured a shift of location, so that about half of output is now from the East Midlands, including the Peak District, and there is a greater reliance in the south, upon imports.

3.4.6 Chemical uses

The dominant Cheshire and South Lancashire-based chemical industry relied upon local salt, coal and pure limestone from the Buxton quarries and the North Wales Coast. The initial Leblanc process also needed to import iron pyrites. The successor Solvay-Ammonia process required similar inputs excluding pyrite. Their main customers were producers of glass, soap, bleach, cotton, paper, paint and plastics. These also rely upon silica sand (widely available in that area), limestone, and readily imported metal ores and oil.

Smaller clusters of chemical production at Tyneside, Teeside, Bristol and East London, also depended variously upon Carboniferous or Permian limestones and chalk.

3.4.7 Metallurgical uses

From the 17th century, the growth of commercial scale iron making in the West Midlands, led to the opening of numerous quarries, which developed as mines in the locally sinuous Silurian limestone outcrops of the Black Country and neighbouring Shropshire, where the Carboniferous limestone was also exploited. As these sources became exhausted, more distant limestones along the Welsh Borders and southern Peak District were exploited.

When iron-making extended to the East Midlands, Lancashire and the Northeast, so companies acquired interests in the nearest available good quality limestones.

When volume steel making began to increase in the 1880s (see Section 3.2.5), this led to the demand for 'basic' furnace linings. These products and magnesium chemicals were dependent upon high purity dolomites mainly from the Permian of Derbyshire, South Yorkshire and Co. Durham.

3.4.8 Abrasives

Wharnccliffe in Yorkshire (Wright 1988) and Lodsworth in West Sussex were two of many early quern stone sources (Peacock 1987). From the Roman period onwards, 'Cullen' (Cologne) stones were imported from Germany.

Peak District quarries, exploiting Namurian sandstones between Hathersage and Derby, met a wide demand for millstones as well as grindstones and pulpstones. Tucker (1987) refers to fifty 'Peak Stone' quarries, and his gazetteer only lists a further 24

quarry areas elsewhere in England; one is at Redbrook in Gloucestershire, this being an extension of Penallt across the Wye, famed for so called, Welsh Stones.

Wickersley in Yorkshire and Gateshead, Co. Durham (both in Coal Measures) were also significant centres of grindstone making, the former being well placed to support the edge-tool industry of Sheffield and north Derbyshire.

Whetstones were sometimes produced as a by-product from these sources but were often sought as the only product in some districts such as Derbyshire and the Blackdown Hills in Devon (Staines, 1993).

3.4.9 Industrial sands

Glass sands have been produced in Surrey, Norfolk, Lancashire and Cheshire, and sandstones were crushed and processed for the same industry in the Staffordshire Moorlands and Pateley Bridge. The Sherwood Sandstone of the Midlands provided the bulk of the naturally bonded moulding sands. High quality silica rock was also in demand from the iron and gas industries until the 1960s, and was provided from ganister mines north west of Sheffield or imported from Wales.

3.4.10 Mines and quarries

Resources, transport and markets exert strong influences on the location of operations. Where there is a market but a paucity of resource, such as for a



Figure 3.14 Many hundreds of Romano-Iron Age rough-out querns litter Wharnccliffe Woods, near Sheffield. © Ian Thomas

reasonably reliable building stone, quarriers are often forced by economic pressure to extend operations below ground. Therefore there is a particular preponderance of mines for such materials in Southeast England. These are reviewed in detail by Sowan (2002) wherein large numbers of examples are cited (see also Section 14).

Mines were particularly prevalent where demand and urban pressures for land were high, suppliers resorted to mining, often in built-up areas from medieval times until c.1900. This was the case for sand at Nottingham (Waltham 1992), Pontefract in West Yorkshire, Bristol and Mansfield in Nottinghamshire, for chalk in Norwich and Southeast London, and for limestone beneath Manchester and Bath (Willies et al. 2011). Elsewhere decorative stone such as 'black marble' and specialist products such as chert were worked underground once available surface sources were depleted.

3.5 Geology

3.5.1 Geological considerations

The main geological divisions (sedimentary, igneous, metamorphic) based on origins, cut across conventional historical working trade groups in the UK:

- **carbonates** – including limestone, dolomite, chalk, marble, dolomitic limestone
- **silica-based rocks** (arenaceous rocks) – sandstone, gritstones, greywackes, arkoses, siltstones conglomerates, breccias, flint, chert, quartzite, silica rock, ganister (as rock)
- **igneous and metamorphic** – basalt, granite, dolerite, diorite, elvan, gabbro, felsites, hornfels, porphyry, andesite, gneiss, tuff, rhyolite, granodiorite, serpentinite, aplite, spilite.
- **slate** is often assigned to its own group and in trade terms traditionally including metamorphic material as well as fissile sandstones, limestones etc. (see Section 3.1.2).

A combination of factors will determine a quarry's location within any geological deposit. These include structure, where bedding and jointing controls the size of blocks, or properties like texture, hardness, chemical composition, colour and its ease to be split, carved, sawn or polished. Geology also determines the method of extraction.

Deposit form - several generic bed forms can be identified which tend to have a profound influence on the style of extraction (based on Thomas 2009):

- massive rock sequences: e.g. the Chalk, Sherwood

- Sandstone, parts of the Carboniferous Limestone
- shallow dipping stone beds inter-bedded with unusable or less useful material, such as shale or mudstone: including much of the Jurassic Stone Belt and upper Yorkshire Dales Carboniferous. (N.B. in some instances such as the Lower or Blue Lias, the clayey material may also be desirable for cement or hydraulic lime)
- granite and other igneous rock massifs: Eskdale in Cumbria, Cheviot in Northumberland and Southwest granite plutons, of Devon and Cornwall or Mountsorrel, Leicestershire.
- complex rock sequences, often highly folded/faulted or steeply dipping beds usually resulting in very irregular workings: e.g. greywackes of Cornwall, Devon and South Cumbria, some metamorphic complexes
- slate (in the geological sense – metamorphic): e.g. north Cornwall, Southwest Cumbria
- isolated/discrete beds, veins dykes, pocket deposits having relatively narrow/restricted surface or lateral extent: e.g. Whin Sill of Northumberland, alabaster in Trent Valley; gangue minerals in vein deposits, which might be used as decorative stone; individual beds of fossiliferous polishable limestone (fossil marbles), such as Frosterley in Weardale
- nodular/lensoid deposits – flint, chert, septarian nodules, small pockets of limestone within a thick mudrock sequence: e.g. North Devon; Kentish Ragstone
- irregular 'soft rock' deposits, unconsolidated workable material, which tends to be found in lensoid or 'indeterminate' sheets within 'waste' material: e.g. valley and glacial gravel deposits.

3.5.2 Information available

Geological maps

Good quality geological mapping is an essential prerequisite in any study of quarries. Fortunately such information is generally available in England, provided by the British Geological Survey (BGS). Basic coverage is at 1:50,000 scale (or in some areas, still 1:63,360 scale) and currently (2014), publication is complete except two small areas of East Anglia and a sheet on the Welsh Border. Most of the maps are accompanied by detailed sheet memoirs, the older ones of which often provide good historical detail on the extractive industries, up to 150 years ago. Regrettably, memoirs are being phased out in favour of shorter 'sheet descriptions'. There is also extensive cover at 1:10,000 (or 1:10,560) scale mainly obtainable on a print-on-demand basis. For

some very limited areas (e.g. of sand/gravel or major limestone resources) and areas of 'classic geology', mapping is also published at 1:25,000 scale.

Relatively recently, with government support, BGS has made much of this mapping freely available online (except at the most detailed scales)². Of particular relevance, the more general geological linework has been edited in a separate series of online maps to depict industrial mineral resources for England. These show the extent of mineral planning permissions (almost all dating since the late 1940s) together with a range of officially designated sensitive areas including, indirectly, archaeological sites.³

In addition to these mineral-orientated reports, BGS and predecessors produce a wide range of more general geological literature and maps, foremost amongst these are the 'sheet memoirs and their related 1:50,000 and 1:63,360 ('1 inch') maps.

Resource and related reports

Although geological in origin, various other series of 20th-century publications have provided generally detailed descriptions of the industry, resources and prospects at the time of publication. These include:

- special reports on mineral resources (generally

- inter-war period) (Geol Survey GB –GSGB)
- wartime pamphlets (WWII and immediately post war) (GSGB) (mainly metallics and strategic industrial minerals)
- Mineral Resources Consultative Committee (MRCC) mineral dossiers (mainly 1970s/1980s) (HMSO) (almost all rocks and minerals except coal and iron)
- Mineral Assessment Reports (mid 1970s to early 1990s) (Inst Geol Sciences - IGS/BGS) (covering most sand/gravel and key Carboniferous limestone areas in England)
- Mineral Resource Information for Development Plans Reports (1995 onwards to mid 2000s) BGS report and map for each '1974' English county, showing all mineral permissions)
- Mineral Fact Sheets (for all main UK mineral commodities) BGS (all downloadable)³
- four small scale mineral resource maps of GB/UK (covering coal – 1:1.5M; metallogenic - 1:1.5M; building stone - 1:1M; industrial minerals – 1:1M).

3.5.3 Distribution of bulk mineral resources

Limestones

Limestone, probably the most versatile rock, is to be



Figure 3.15 As in Wales, the metamorphic slate industry in England has generally been comparatively well recorded. It is concentrated in Cumbria and as here on the north coast of Cornwall. © Phil Newman

found in every '1974' English county (Harris 1982) . However, the deposits in Cheshire (at Astbury) only extend over a few hectares and those in Cornwall also are very small (Kirkham 2004).

Three main categories of limestone can be defined, for the purpose of this assessment as types:

1. older 'hard' limestones
2. Mesozoic and softer limestones
3. Chalk

The older, harder limestones (Type 1) are all located to the north west of a line from Lyme Bay in Dorset to the Tees Estuary. The muddy limestones running from Millom to Tebay in Cumbria, previously known as the Coniston Limestone, are now classified as belonging to the Dent Group of the Upper Ordovician. The Silurian includes the Aymestry and Wenlock Limestones, which have sinuous outcrops along the Welsh border counties from May Hill in Gloucester to Stourport, in Worcestershire and as far north as Telford in Shropshire. Further deposits form small, but historically very important, sources in Dudley and Walsall, in the West Midland areas where they were mined intensively. Other historically significant resources belong to the Devonian, outcropping between Plymouth, Newton Abbot and Brixham in Devon; in some instances these are tectonically altered but not fully metamorphosed into marble in the Ashburton and Buckfastleigh Area (Walkden 2015a & b). More minor occurrences are found between Lostwithiel and St Columb in Cornwall.

The most important limestones commercially, are those of Carboniferous Age. In most of England (except the far north) these are concentrated in the lower half of the Tournasian (Lower) and Visean (Upper) subdivisions (previously known as the Dinantian).

The southernmost Carboniferous limestones outcrop in the Wellington to Tiverton area, and sporadically westward into North Devon. The backbone of the Mendip Hills from Frome to their extension on the coast at Weston-super-Mare in Somerset, comprises a thick sequence of folded limestones. Other local, large but detached outcrops are found around Bristol. West of the Severn, they also encircle the Forest of Dean coalfield. Small outliers in Shropshire – in the Clee Hills

and inliers near Telford and around Oswestry – and associated with the South Derbyshire/ Leicestershire Coalfield, have all been intensively exploited.

An important source today, and for at least the last two centuries, has been the massive limestone block of the White Peak of Derbyshire and Staffordshire. This has supplied exceptionally chemically pure limestones.

Irregular, narrow outcrops between Clitheroe in Lancashire and Skipton in Yorkshire, become more extensive further north in the Yorkshire Dales, the third important, nationally significant producer. The same formations continue westward, skirting Morecombe Bay in Lancashire and beyond, across the Furness Peninsula in Cumbria. They also define the northern rim of the Lake District from Cleator Moor to Kirkby Stephen then skirt along the eastern edges of the Vale of Eden, to Brampton. North of the line from Brampton to Hexham in Northumberland and Craster to the Scottish Border (with the exception of an area around the Cheviots), they comprise thinner limestones, each forming part of a cyclical deposition of rocks including limestones, shales and sandstones.

Limestones of Permian age (significantly dolomitic) occur as a band only a few miles wide, from near Nottingham in the south, through Derbyshire and Yorkshire, with only minor breaks, to the Co. Durham coast.

The younger, softer limestones (Type 2) of the uppermost Triassic (Rhaetic Stage) and much of the Jurassic, constitute a great swathe of English countryside from Lyme Bay in Dorset to the North Yorkshire Moors, often known as the Jurassic Stone Belt. Where limestones occur here, they are in discrete beds, interlayered with a variety of other rock types. The belt forms the main substrate of the South Dorset, East Somerset, Northamptonshire uplands, Lincoln Edge and, most typically, the Cotswolds. The lowermost beds along the western edge in Dorset, Somerset, Gloucestershire and Worcestershire comprise the White Lias (Triassic) but above and more extensive, are the Liassic Limestones, which exhibit important hydraulic properties. Stratigraphically above these, limestones (often oolitic) alternate with clays. These

Table 3.4 Historical coverage by rock type and area

Commodity	Poor	Medium	Good
Limestone	Most other areas	Mendips/Cotswolds/Derbys	York Dales/ S Cumbria
Dolomite	All		
Sandstone	Most areas	Mid-Pennines	
Igneous rock			South West England/Leics
Sand/Gravel	Most other areas	Trent	
Slate		Parts of Cumbria/Cornwall	



Figure 3.16 Sand and gravel extraction, usually considered ephemeral, has been almost entirely neglected by archaeologists, but was vital for every community. Croxden in Staffordshire exploiting Sherwood Sandstone, began in earnest in the 1930s. Output increased here making it one of Europe's largest producers, with a capacity of 2 Mtpa in the 1990s. © Graham Hogg, Geograph

have provided our best known prestige building stones, notably Bath, Portland, Weldon, Clipsham, Ancaster etc, and the decorative Purbeck 'marble'.

From the Howardian Hills in Yorkshire, via the Hambleton Hills onto the North Yorkshire Moors, limestones are present, but do not dominate the Jurassic as they do in the south. In the Cretaceous, the Ragstone of Kent is significant and there are other minor limestones in the Weald, Norfolk and Lincolnshire.

The Cretaceous Chalk (Type 3), a soft and often pure limestone, underlies much of southeastern England (excluding the Weald) from East Devon to King's Lynn, although it is often obscured by more recent deposits in the Hampshire and London basins and much of the eastern half of East Anglia. Outcropping chalk is common on Salisbury Plain, and the North and South Downs, and resumes in East Lincolnshire and East Yorkshire. However, the 'pure' composition of the Upper Chalk does not apply to the so-called grey chalk making up much of the thin Lower and Middle Chalk. This contains c.70% calcium carbonate, the remainder being clay minerals.

The only Palaeogene limestones of note are Quarr Stone and less significantly (in historical terms), Bembridge Limestone, both on the Isle of Wight.

Along the shorelines of the Thames Estuary, septarian nodules (hard masses of calcareous mudstone within the London and Ipswich Clay - Eocene) were historically important.

Modern 'limestones' are being created (and have been used) in the form of shell sand, notably along the Cornish Coast and Isles of Scilly.

Sandstones

The distribution of sandstones in England is far more difficult to define than limestones, as they vary from some of the hardest rocks in the UK, to unconsolidated sands or conglomerates and from soft, sandy mudstones

to extremely hard, pure quartzites. As a group, they occur very widely, particularly within the older sequences of the north and west (Harris 1977a).

The oldest, belonging to the Neoproterozoic (younger Pre-Cambrian), occur in small areas near Shrewsbury in Shropshire and in Charnwood Forest in Leicestershire. Cambrian quartzites have been quarried at Nuneaton in Warwickshire, Telford in Shropshire and near Birmingham. Ordovician and Silurian greywackes (alternating sequences of sandstone and mudstone) occur in Shropshire, Ingleton in the Yorkshire Dales and southern Cumbria. Similar rocks of Devonian and Carboniferous age were formed in South and North Cornwall, much of North Devon and the Quantock Hills in Somerset.

The Devonian ('Old Red Sandstone') of the Welsh borders is often coarser, softer and more variable in composition, but was used locally as a building stone in the past.

Economically, the most important sandstones belong to the Carboniferous and are generally associated with all the Coalfields. These mainly belong to the Millstone Grit Group (sandwiched between the Carboniferous Limestone and Coal Measures) and either fringe the Midlands and Pennine Coalfields, or make up the backbone of the Pennines themselves from the Dark Peak to Catterick in North Yorkshire. Beyond this, and in the Yorkshire Dales, similar rocks form part of the Yoredale Group (especially the Stainmore Formation), ranging on up to the Northumbrian coast. Similar, but sometimes weaker, sandstones are found in many of the Coal Measures themselves. These have been widely exploited in West Yorkshire. The Pennant sandstones of the Bristol and Forest of Dean coalfields in Gloucestershire were also significant.

The white and red sandstones of the Permian and Triassic ('New Red Sandstones') are usually softer and

are widely dispersed across the Midlands from the Welsh Borders across Staffordshire to Derbyshire, Nottinghamshire and Warwickshire. Generally comparable beds (mainly Sherwood Sandstones/Mercia Mudstones) are found, in large part obscured by drift deposits, in Cheshire, Lancashire, the Vale of York and West Cumbria.

Sandstones make up only a relatively small proportion of the Jurassic and Cretaceous, but in the former, those of the Lower Greensand and Hastings Beds and those over much of the North York Moors, are noteworthy. The well-known sarsen stones of Wessex are residual Palaeogene materials.

Although most sandstones are employed as a building stone, or as an aggregate, some stone is sufficiently pure, or capable of processing, for use as a source of silica; modern examples are near Pateley Bridge in the Yorkshire Dales and Oakmoor in Staffordshire (Highley 1977).

Igneous rocks

By comparison with Scotland and Wales, England possesses relatively limited resources of igneous rock (Harris 1977b).

The best known are the granite 'bosses' of the Southwest (Scilly, Lands End, Carnmenellis, Hensbarrow (St Austell), Bodmin Moor and Dartmoor). Lundy Island is composed of granite and in the north there are granites in Eskdale and Emmerdale in the Lake District and at Shap in Cumbria and Cheviot in Northumberland. Some of these, especially in the Southwest, were historically very important sources. In modern production terms, by far the most significant are the cluster of inliers around Charnwood Forest in Leicestershire. These vary considerably in age and type, including granodiorite, diorite, dacite, andesite and volcanics. Some similar rocks occur at Nuneaton in Warwickshire and near Telford in Shropshire. In Devon and Cornwall, there are numerous exposures of intrusive rocks (i.e. dykes and sills - mainly gabbros and diorites locally often referred to as 'greenstones') in the same general zone as the granites, together with other volcanic rocks. Granite dykes in Cornwall are known locally as elvan.

The isolated inlier of andesite on Mendip in Somerset has been exploited, as has the Whin Sill, a thick dolerite, which can be tracked from Middleton-in-Teesdale (Co. Durham), then edging the Vale of Eden along the South Tyne and Hadrian's Wall, to the coast at Bamburgh in Northumberland. Also in the Northeast, are dykes radiating from the Cheviot granite, and a swarm in southern Northumberland is associated with the Palaeogene volcanicity of Western Scotland. A single dyke of the same vintage runs from Carlisle in Cumbria towards Whitby in North Yorkshire.

A number of intrusive sills as well as lava deposits are present around Wolverhampton, the White Peak of Derbyshire, and along the counties bordering the Welsh Marches from Oswestry to Telford, Church Stretton and the Clee Hills in Shropshire, to Kington in Herefordshire, Abberley Hills in Worcestershire and the Malvern Hills bridging the latter two counties.

Metamorphic rocks

Of the metamorphic rocks, slate is the only group which has been of significant commercial importance in England (Crocket 1975). The most important producing area is Cumbria where slates have been extracted on a large scale. There are two substantial belts. The highly cleaved Borrowdale Volcanic Group (Ordovician) sweeps from Millom, north eastwards across the central Lake District. Within this Group, the Birker Fell, Seathwaite Fell and Tilberthwaite Formations are the most notable. These are the so-called 'Green-slates'. To the south, Silurian rocks run through the Furness area across the northern shores of Windermere and produce bluish grey slates from the Brathay and Wray Castle Formations.

In Southwest England, the main operations have been centred around Tintagel (especially Delabole) and Fowey in Cornwall, also Tavistock and Dartmouth in Devon.

In Leicestershire, a much smaller former producing area lies in Charnwood Forest, where the Swithland Slates were quarried south of Woodhouse Eaves and around Groby.

Other metamorphic rocks (Harris 1977b) are extremely limited, being confined to zones influenced by granite or other intrusions where hornfels and other altered rocks (principally in Cornwall and Devon) were formed e.g. around Meldon, north of Dartmoor and the 'exotic' Polyphant stone beyond the Bodmin granite. At Start Point in Devon and The Lizard in Cornwall, there is a range of metamorphosed rocks, including at the latter, serpentinite (ophiolite). Metamorphosed shales, known locally as 'killas', were an important building stone in the zones surrounding the granite in the Southwest and quarries existed to exploit them. They were much sought after for building stone because of their uniform flatness which enabled rapid construction.

Very few true (i.e. metamorphic) marbles are present in England although a number of highly polishable limestones were known in the trade as marbles (see Section 3.1.2).

Sand and gravel

The majority of sand and gravel in England has been won from two main sources (Archer 1972). Firstly, the deposits associated with Pleistocene glaciations, with those generated by the melt-water rivers being more

commercially significant than the sands and gravels dumped by the ice itself. Secondly, the gravels formed as numerous terraces along river valleys, sometimes preceding, but more often following, glaciation, through to the present day (Bowen 1999). The more recent, lowermost, terraces are very often covered by spreads of silt and clay, mapped as alluvium. Industrially, the most significant have been the deposits of the Thames (predominantly flint) and Trent Valleys (mainly reworked Sherwood Sandstone pebbles). In addition, some of the forerunners of these river systems, such as seen in the Vale of St Albans (proto-Thames), or the Coventry-Towcester areas (produced by the so-called Bytham River) in the Midlands, have been important. Almost all other river valleys and indeed every English county, have sand and gravel deposits.

Great sheets of glacially-related sand and gravel mask most of lowland Cheshire and Lancashire, as well as the Vale of York and the East Anglian coastal strip. These tend to be extremely variable, less well sorted in terms of particle size and composition than river gravels.

The other substantial source, namely sea dredged aggregate, is greater in the UK than for any other country, but is outside the scope of this assessment.

In addition to these 'superficial' deposits of sand and gravel, there are 'solid' bed-rock resources of the same basic type. Most notable are those of the Sherwood Sandstone Group, ranging from Nottingham across Derbyshire and Staffordshire into neighbouring areas of the West Midlands. Other sources in this category include the Lower Greensand (especially the Folkestone Beds) of the Weald in Kent, and Bedfordshire. Eocene sands have also been excavated in Hampshire and Berkshire. Most of these are 'soft' (i.e. relatively poorly cemented) sandstones and so easily crushed to produce sand.

Very pure silica sands suitable for industrial applications (e.g. moulding sand, glass making) occur in Lancashire, Cheshire, Norfolk, Surrey and Lincolnshire (Highley 1977).

'Modern' beach sands and gravels have provided a resource in many coastal areas, most notably at Dungeness in Kent, along the former shorelines of the wash (Fen Edge Gravels in Lincolnshire and Cambridgeshire) and the Lancashire Coast.

Flint and chert

Flint and chert do not fall readily into these main categories. Both occur in chalks and other limestones respectively, but, particularly in the case of flint, have also been winnowed and weathered out as extensive residual gravel deposits over much of south eastern England. Chert is found in the Carboniferous limestone of the Pennines and mudstones of Devon and Cornwall.

Ballast, by-products and 'recycling'

In the building industry, a generic term for sand and gravel, especially in southern and eastern England was 'ballast'. It was the ballast unloaded by ships which provided a substantial proportion of aggregates in quayside areas, from Newcastle to Hull in Humberside, Kings Lynn in Norfolk and London. Also introduced as ballast, chalk from the south and limestone from the Northumberland coast, fed the kilns of Tyneside. Peacock (1998) devotes a chapter to the subject (also pointing to pitfalls in over-interpretation) and Buckland and Sadler (1990) provide a chronological review.

Robbing stone from existing buildings has long been a short cut to the otherwise arduous task of winning and working stone; a practice which became especially prevalent with the reuse of materials from abandoned Roman structures and following the dissolution of the monasteries. This activity was recognised by early researches into Roman Wroxeter (Pearson 2006) and other useful examples are given by Stocker and Everson (1990).

Further sources of stone include by-products or co-products, such as china clay sand (mica, produced from washing china clay also known as stent), limestone gravel arising from vein mineral processing, sandstone discard from coal mining, and waste generated by building stone operations as well as cast or ground slag from smelting activities.

3.6 Historical and other non-archaeological research

'Stone quarrying is an industry to which references in medieval records are more numerous than enlightening' L F Salzman (1923).

3.6.1 Summary – general sources

Coverage in this section is discussed at national, regional, local and site-based level respectively.

Most research on bulk minerals tends to be multidisciplinary, bringing together historical records, geology and archaeology but particularly the first two, sometimes supported by brief verification in the field, but often without detailed survey. This is especially the case in respect of building stones.

The history of extracting bulk minerals in England as a whole is not particularly well covered, but there are some good 'regional' and many detailed local reports. Where accounts have been produced, they are heavily skewed towards building stone and are largely chronologically, geologically or geographically constrained. There is a marked concentration of broad 'review' publications between 1938 and 1970, and of



Figure 3.17 Jope demonstrated that the Saxons had revived (if not continued) the extraction at many traditional Roman sources by surveying church stonework. [squares = Bath/Box; crosses = Taynton; dots = Barnack]. After Jope 1964

more detailed local or site investigations after 1970. Alongside these are their primary documentary sources, which either contain some historical information or, with the passage of time, have become historical sources in their own right. Documents might include building accounts, leases, wills, agreements, grants, licences, rights to work or transport stone, land ownerships, company and official records, area/property surveys and plans, bills of sale. Important printed sources include specialist directories, maps and official reports. Publications from other disciplines such as geological surveying and by railway researchers, can often prove to be invaluable; indeed sometimes they are the only available sources, in respect of the extraction of these generally low value, high volume, relatively mundane commodities, which were often exploited informally.

Occasionally, extensive documentary material has emerged. From primary documents it is known, for example, that Winchester controlled by Royal Grant (Galbraith 1920, 382-400) the Quarr stone on the Isle of Wight (used widely in Hampshire); Salisbury Cathedral employed (and still uses) Chilmark Stone; and that a variety of stones were employed in Canterbury city and cathedral (Tatton-Brown 1990, 70-82). Documentary evidence from building accounts survives for many great buildings, such as Windsor Castle, Eton College, Hardwick Hall, Dover Castle, Canterbury Cathedral, Chatsworth House, Vale Royal Abbey and Westminster Abbey, some of which have been published (Salzman 1970; Durant & Riden 1980, 1984; Sowan 2002; Thomas & Cooper 2008; Hignett 1935).

In addition to documentary evidence, there are important clues concerning the development of the

industry in the petrography of its products (notably honesstones, grinding and milling stones and, most significantly, building stones) but there is usually lack of robust connection with source sites. A major field of research has attempted to correlate stone observed (usually based on petrology) in the fabric of buildings, nominally dateable by architectural detailing, with putative stone sources. There have been varying degrees of success (Peacock 1998; Haywood 2009; Strategic Stone Study⁵).

All these particular sub-sectors have been reasonably well, widely, and in some instances, systematically researched.

For example, Jope's contribution to matching buildings and stone sources is exemplary as a classic work covering the whole of southern England and large parts of the Midlands (Jope 1964, 91-118). He reported on dressings, ashlar and sculptured stone from 500 locations, largely parish churches from the 8th to 11th centuries, almost all south of a line from the Wash to the Severn Estuary. A contemporaneous account (Taylor & Taylor 1965) calculated that there are still over 400 English churches which incorporate Saxon masonry, in the main, relatively close to the southern and eastern coasts.

3.6.2 National coverage

The earliest survey of England that referred to stone (largely for building) was Domesday in 1086 but this records only eight English quarries: Taynton in Oxfordshire; two sites at Lympsfield in Surrey; Grittenden, Iping, Stedham and Bignor, all in Sussex; Whatton in Nottinghamshire; the last two are for millstones. The distribution is geographically incongruous, the Sussex locations probably reflecting familiarity of the early surveyors with the area. Many other active sites were almost certainly omitted as not taxable in their own right.

Parsons (1990a) and Salzman (1957) both carry comprehensive accounts up to the dissolution of the monasteries. In the later 18th century and early 19th century, the government commissioned a series of county-wide surveys, ostensibly of farming but some of which strayed into mining and quarrying. Of these, the most detailed narrative on extractive industries comes in Farey's work on Derbyshire and surrounding areas (1811).

The earliest comprehensive national studies of building stones *per se* were conducted by the Geological Survey of Great Britain in 1839, to identify suitable stone for the rebuilding of the Palace of Westminster after the fire of 1835 (Barry et al. 1839). Of necessity, these combined history, field visits and geology and reported

on 80 English stone sources, mostly established quarries. Not only did they consider a range of quarried stones, they attempted to gauge performance over centuries by examining buildings from known sources. The material collected formed the starting point of what was to become the UK's largest building stone collection.

Robert Hunt (1860) had begun gathering data concerning mineral production in the 1850s as Keeper of the Mining Records Office at the Geological Survey. In 1858, he turned his attention to bulk minerals, but this proved such a daunting task that, apart from a partial survey shortly afterwards, it was discontinued until 1895, when returns became mandatory under the 1894 Quarries Act. In the interim, data on all underground workings, including stone, were published as a requirement of the Metalliferous Mines Regulations Act 1872. From 1896 to 1938, detailed annual statistics and lists of operations were officially published. There is then a break in the detailed series until the 1960s, when publication was resumed, albeit on a different basis.

In the early 20th century, there were a number of more technically-based, but landmark accounts of the quarrying industry. These now constitute historical material, notably Greenwell and Elsdon (1913), Searle (1935), North (1930), Eckel (1922) and Knibbs (1924).

Probably only two reviews can claim to approach national historical coverage, both of which are seminal and comparatively recent, although the first is restricted to building stone and the second combines history and archaeology. Alec Clifton Taylor's work (1972), *Pattern of English Building*, comprehensively described the building materials (principally stone) throughout England, especially over the last five centuries. In particular, he linked buildings to their stone quarry sources, but rarely engages with the archaeological detail of individual sites.

The second, Stanier's (2000) *Stone Quarry Landscapes*, is probably unique in its chronological (prehistory to c. 1930s), thematic (building stones, aggregates etc.) and national scope. By adopting an approach which balances the historical, archaeological and geological, he outlines an holistic framework for addressing an otherwise largely neglected aspect of England's formative landscape. Stanier sets out various typologies and checklists for recording, from broad brush to site level, some of which are utilised as templates in modified and amplified form in other sections of this bulk minerals analysis. Separately, Stanier (1995) complemented this coverage by annotating a representative selection of BGS's photographic collection and (1985c) provides an introductory overview.

By contrast, Pevsner's, *The Buildings of England* series (with a few notable exceptions, e.g. Clifton-Taylor's own contributions), at best often only makes

disproportionately meagre mention of stone; not only is the coverage patchy, the quality of stone assessment is also often variable and sometimes questionable. At the same geographic level, the *Victoria County History* series provide a better insight into former quarrying, in those volumes where it is reported.

Between 2006 and 2012, English Heritage managed the Strategic Stone Study, a survey of building stone and quarries in England, covering about two thirds of the country and almost all the main producing county areas. Coverage of the remaining areas is anticipated. In parallel, the BGS's Britpits system is an inter-relational database of all extractive sites linked to a GIS (geological and topographical).

Two notable national conferences on building stone were held in Loughborough in 1988 and York in 2005. Papers from historical and archaeological perspectives were presented and published (Parsons 1990a; Doyle et al. 2008) and vary from national to site coverage. A conference in Wales in 2002 (Coulson 2005) covered some English aspects, including cross border trade.

Hudson (1971) covers the development of the high quality building stone industry, Lott (2008) the Victorian stone industry, and Hughes (in Wood 2003) the contribution made to stone roofing by slate quarrying. Price (2007) provides a 'complete sourcebook' of decorative stone of which a small part is devoted to domestically produced material.

Outside the building stone sector, Earle (1971; 1974) produced two national accounts of the development of the UK roadstone and road surfacing industry, both of which provide useful descriptions of the 20th-century quarry sector. Francis (1997) describes the cement industry up until the First World War and the Cement Kilns website¹ provides a detailed historical and technical analysis of UK cement industry, works by works.

3.6.3 Regional and local assessments

Coverage at a regional level has tended to be fragmented; although very good in parts, there are some, perhaps surprising, omissions. Many of the main centres and players in the 20th-century industry are well described, although the quality and objectivity of some company histories, or aspect studies, could be open to challenge. The division between various levels is, of necessity, somewhat arbitrary. Some works (e.g. by Stanier and Johnson), combine historical and archaeological research.

Published historical work includes: Stanier (1999; 2015) on the Southwest, especially granites; Thomas (2006) on Mendip limestone; Sowan (2002) on the Southeast; McGrath (2007) on Charnwood igneous

rocks; Thomas (1999 & 2000) on the Peak District; Johnson's work on lime in the Yorkshire Dales (2002, 2010a), Westmorland (2013) and central Pennines (2010b); Cooper (2008) on Trent Valley (sand and gravel); Kent Underground Group (1991) on Kent/East Sussex; Jope (1964) on southern England and the Midlands medieval stone; Alexander (1998) and Lott (2001) on the East Midlands; Thomas (1996) on the 'grey slates' of the Peak District; Prudden (1995) on Somerset building stone; Watson & Musson (1996) on Shropshire; Cordiner & Brook (in press) on Sussex building stones. W G Hoskin's major work, *Devon*, contains a useful chapter on the county's building materials and discusses the location of several quarry sources (Hoskins 1954, 258-79), though is now somewhat dated.

Many authors deal with stone at more local level (i.e. between regional and site levels). On sandstones (or mainly sandstones), the work of Blacker (1995 & 1996) covers Nidderdale in Yorkshire; Kitching (1977) on the Macclesfield area; Allen (2004) Norfolk carrstone; Thomas (2012) on Lower Derwent World Heritage Site; Revell and Baldwin (1985) on Rossendale; Moorhouse (1990, 2007) and Walton (1940) on Southwest Yorkshire; Burgess (2008) on Surrey mines.

Limestones (or mainly limestones) have been covered by the following authors: Sutherland (2003, 2005) on Northamptonshire; J Thomas (1998a & b) on Dorset; Purcell (1967) on the sources for Cambridge; Arkell (1947) on the sources for Oxford; Ireson (1986) on Stamford; Senior (1999) on Rievaulx; Blacker & Mitchell (1998) on 'marble' at Fountains Abbey; Blacker & Mitchell (1999a & b) on 'Egglestone marble', Co. Durham; Jeuda (1999, 2000a, 2000b) on Caldron Low, Staffordshire; Stocker (2007) on Kentish ragstone; Beadle (1997) on Teesdale; Anon (1949) and I A Thomas (2008) on Hopton Wood stone in Derbyshire; Senior (1990) and Hayfield & Wagner (1998) on Hildingley stone, Yorkshire; Myerscough (2004; 2007) on the Corallian of Northeast Yorkshire; Popplewell (1988) on Swanage in Dorset; Walkden (2015a & b) on Devon 'marbles'.

Sand and gravel do not appear to have been covered historically at this level, although some planning publications, such as Sand in Cheshire (Mackay and Schellmann et al. 1970) present background material and Harrison et al. (2007) traces the evolution of the industry over the last 60 years in the South Midlands.

The following include both 'cluster' and individual site analyses. The Bath stone industry has been described by Huggins & Pickford (1975), Bezzant (1980), Beazer (1981), Perkins et al. (1979), Price (1984), and Hawkins (2011); it is also covered as historical background to a major archaeological study by Willies et al. (2011).

In the North Cotswolds there are archaeo-historical investigations by Aston (1974) on Stonesfield, Oxford; Bick (1971) on Leckhampton in Gloucestershire, and Price (2007) on Whittington and Cheltenham in Gloucestershire.

Various historical aspects of Purbeck stone have been reported by Benfield (1940), Saville (1973, 1986, 1996), Popplewell (1988), Leach (1978) and Stanier (1996). Portland stone has been covered by Warland (1941), Stanier and Cox (2007), and more recently by Hackman (2014), whose work has made the important link between the source and the buildings of London.

Historical accounts of the Cumbrian slate industry can be found in David & Brambles (1987; 1992) for various Westmorland sites, Tyler (1994) on Honister, and Cameron (2005) on Coniston. For other metamorphic slates, Sharpe (1990) writes on the Tintagel coast, Lorigan (2007) regarding Delabole and Brittan & Ramsey (2007) on Leicestershire

On Dartmoor and other Southwest granite operations, general reference is made in Harris (1966) and Newman (2011, 181-92). Specific reference to Foggintor are in Brewer (1997) and Pew Tor in Harris (1981). Other Princetown quarries are discussed in Hallett (1994) and Dell and Bright (2008). Stanier (1985b; 1986a; 1987) covers the Dartmoor quarries as well as those of Cornwall including the Cheesering and De Lank. Slate, whetstones and Beer Stone are among the 'mined' materials discussed by Edwards (2011).

Accounts for some of individual sites include Scott and Gray (nd) and Edwards (2011) on Beer chalk mines, Devon; Fenn and Cox (2007) on Westleigh, Devon; Fenn (2009; 2009/10) on Bardon Hill, Leicestershire; Arthur (2002), on Darrington, West Yorkshire; Dunn (2004) on Stoneycombe Devon; Pushman (1995) on Swanworth Dorset; Kirkham (2004) concerning Astbury; Cheshire; Adams (2007) and Powell (1999) on West Midlands limestone mining; Bishop (2001) in respect of Quarr stone; Thompson (1995) on Grinshill sandstone; Sagar-Fenton and Smith (2005) on Lizard serpentine; Staines 1993 on Devonshire whetstones.

Historical narratives on transport, and in particular quarry railways, are numerous, examples being Peaty (2006) relating to the whole of Hanson Group's operations across the UK, Messenger (2005) on Southwest England, Bowtell (1979) on Yorkshire reservoir construction railways, Lead (1979) on Caldron Railway and Canal, Tebb and Smith (2007) on Crich in Derbyshire, Harris (2002) on the Haytor Granite Tramway in Devon, and Savery (1979) on the development of quarry transport in general.

Darlow and King (1995) have charted the changes in a century of quarry legislation.

3.6.4 Additional sources

More than eighty building stone guides have been published for cities, towns, areas and villages which seek to identify stone types and often sources (English Stone Forum website;⁴ and copies of which are held at the National Stone Centre. Many geological trails do the same, occasionally relating to individual buildings e.g. Chatsworth House in Derbyshire (Thomas and Cooper 2008).

Local Geodiversity Audits/ Action Plans (LGAPS) often carry inventories of local building materials and their sources (Natural England, the Geology Trusts and Geo-Conservation UK are contacts in the absence of a comprehensive list), those for Gloucestershire (Owen et al. 2008) and Cornwall (Spalding et al. 1999) being good examples of many.

3.7 Technology

3.7.1 Exploration

The first step of exploitation is prospecting. However, unlike the mining of more valuable minerals such as metal ores or coal, the search for bulk minerals was usually less sophisticated. In the main it would have comprised trial trenching or pitting based initially on extensions to known outcrops or local knowledge of, for example, the absence or presence of waterlogged ground and weathered surface material found in fields. It is highly unlikely that any substantial evidence of these activities survives, except perhaps trial holes, which are unlikely to be recognisable. Hushing may have been applied (Trueman et al. 1999, 16) to reveal bedrock, and is known to have been a technique used for limestones in the Pennines (Johnson 2010c).

3.7.2 Extraction - manual methods

Flint for prehistoric implements (see Section 2) was first gathered at surface and later mined. Some stones for implements were extracted by surface working. Processing comprised knapping and in some instances polishing, and was sometimes carried out at the point of excavation, though often a supply of flint may have been transported and stored as a raw material to allow the flexibility of manufacturing a variety of tools as and when needed. With other raw materials, such as those used for axe manufacture, rough outs were transported over considerable distances before finishing (Clough 1979; Bradley and Edmonds 1993; Edmonds 1995; Waddington 2004).

Most material quarried or gathered before c.1700 AD would have been won and processed entirely by hand, with the exception of the use of animals to provide

haulage and sometimes power. In general the low market value of bulk minerals has often prohibited far more costly mining, in favour of quarrying. It is doubtful if underground extraction of these commodities ever accounted for more than a tiny fraction of national output. The only exception is the period around 1800 when the West Midlands limestone mines were at their peak, and the area south of the Thames was becoming somewhat more reliant upon mined stone and chalk. Even in these cases the areas of surface operations for sand and chalk would greatly exceed the extent of mines. It is likely that only rocks that had decorative or specialist properties would have been considered worth pursuing underground.

Hand tools

It is often observed of quarry tools that their form has remained unchanged for centuries, or even millennia.

Almost all medieval and most Roman hand tools used by stone hewers would have been comparable with styles still in regular use in thousands of hand-worked quarries until 1914. For hand carvers in studios and conservation work even today, the implement styles are still essentially the same. The major changes came in the materials used, not in radically different designs, so alloy steels in the late 19th century began to make edge tools much tougher than anything the most skilful blacksmith could make.

Descriptions of Roman artefacts (Blagg 1976; Pearson 2006), and medieval practices (Stanier 2000; Salzman 1957; 1970), can be compared, and match closely, the late-19th and early-20th-century tools (Greenwell & Elsdon 1913; Clifton-Taylor & Ireson 1986; Warland 1953; Arkell 1947).



Figure 3.18 Roman or Norman masons would have easily recognised the form and purpose of these modern apprentice's tools – mallets, hammers, chisels, squares. Effectively only their composition has changed over the last century or so, making dating of earlier finds problematic.

© Ian Thomas

Roman implements included heavy (sledge type) hammers, adzes, punches (pointed chisels, also known as points), straight chisels, drags (wide chisels), shovels, crowbars utilised as levers, bow-powered drills, and saws (often two handed) (Blagg 1976). Jadds (or jadd picks or racers i.e. narrow pointed picks) were presumably also used, as they are known from sites beyond Britain. For splitting stone along a groove or series of grooves (wedge pits), iron or wooden wedges were employed – the latter were wetted to make them expand. Stone blocks were lifted using a device known as a three legged lewis to move them from quarry faces to processing areas and to raise them into position on a structure.

As early as Norman times, wedges would have been replaced or supplemented in part by plugs and feathers, and bow-powered drills by jumper bars/rods. These jumper/jumping bars (sometimes also known as drills) are end-pointed iron rods, hammered and turned into a rock to produce a line of vertical holes into a bedding plane or upper surface. Into each hole is placed a small, slightly tapered bar (plug), on either side of which feathers, (i.e. thinner, iron strips with out-curving tops) are inserted. The plugs are then hammered in sequence until the stone splits along the line of holes. A modification, perhaps introduced as late as the 19th century, was the swell jumper, (a jumper with an added weight to increase downward strike). Although plugs and feathers are still employed today, the holes are usually made by compressed air drills.

References in medieval and slightly later accounts are made to gavelocks (crow bars), cornaibis (also possibly crow bars), weggs (wedges), bechis (spades), pulyngax (poleaxes), kevels (hammer axes), broacheaux (broach axes), pycons (picks), houis (hows) and triwlis (trowels), as well as shovels, sledges (hammers) and skales (hammers for cleaning rough faces/edges i.e. for scaling) (Salzman 1970; Knoope & Jones 1938; Jope 1964; Stanier 2000).

For some softer rocks, especially some of the Permo-Triassic sandstones in Merseyside, South Lancashire and Cumbria, as well as many Jurassic limestones, narrow picks (jadds) were used in quarries until the Second World War, to cut vertical grooves to separate out blocks. Before the introduction of compressed air drilling (in some quarries as late as the 1930s), holes were also still bored for blasting using the traditional long rods or jumpers (by 1900 known as steels), hammered in and turned using tongs.

3.7.3 Mechanised extraction techniques

Drilling

For a short period, steam powered drills were used

in Cornwall, for example in the 1880s (Stanier 1999). After the turn of the century, steam was reserved for electric power or compressed air generation (produced centrally) for channelling (cutting deep grooves into rock) or blast well drilling.

Compressed air driven (pneumatic) rock drills were developed outside the UK in the mid 19th century but perhaps the best known advance was Samuel Ingersoll's drill invented in 1871. Powered drills did not come into widespread use even in medium to large scale UK quarries until the very end of the 19th century. Electric hand-held hammer drills were in use before the First World War, powered from a central generator.

Smaller powered drills were employed to produce a series of holes for wedging apart blocks (using plug and feathers in dimension stone quarries), or preparatory to blasting, either of the face (primary blasts), or breaking up large fallen blocks (secondary blasting or 'popping').

By the 1930s almost all except the smallest building stone quarries were using pneumatic hand held drills, replacing hand driven 'steels'. More recently, there have been many technical improvements in blast hole drilling: tracks replacing wheels, control over the direction of the cutting head, in the use of water and air to remove rock chips, increases in hole depths/diameters, reduction of blade wear, lubrication, power sources etc. The introduction of down-the-hole hammer drills in the 1950s-60s, then hydraulics, proved to be major breakthroughs.

Blasting and breakage

Although gunpowder (usually known in the trade as 'black powder') was employed in Europe in Alpine road building as early as 1481, its application in English rock quarries does not appear to have been recorded before 1665 (Hollister- Short 1994, 148). Possibly the earliest reference to the use of 'black powder' in British quarries was by Boyle in 1671. However, Hollister-Short logically



Figure 3.19 Evidence of blasting an a fragment of Devonshire granite. © Phil Newman

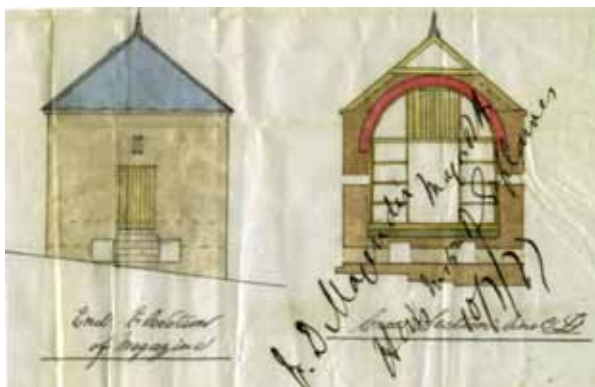


Figure 3.20 Powder magazines with their strong walls and being remote from working areas, may survive long after all other evidence has been lost. © NSC / Tarmac

suggests that Boyle's observations related to the extraction of stone on Portland for the 1669s rebuilding of London after the Great Fire. The circumstances were exceptional: resources on Crown Land and high levels of demand probably justified the extra costs, and Wren had the right connections and hence access to ordnance. In more conventional situations, expense, official controls on usage, availability, and safety considerations meant that gunpowder (effectively the only explosive available and a relatively mild one) was still little used in British quarries before about 1800.

Blasting was made more reliable by the development and invention of safety fuses by Bickford in 1831. The next and far reaching innovation was the establishment of dynamite manufacture by Nobel in Scotland in 1871. This was followed again by Nobel's improved fuses in the 1880s.

The Gunpowder Act 1860 outlawed storage of amounts of more than 200lbs (91kg) in non-specialist facilities, and the Explosive Substances Act 1875 required local authorities to regulate stores, heralding the widespread building of magazines associated with quarries. Nitroglycerine and TNT formed the basis for a whole host of blasting explosives: HM Inspector of Mines Annual Report for 1900 records about a dozen high explosive proprietary brands but even in 1909, 80% of quarry blasts still used gunpowder. By 1930, the application of high explosive equaled that of black powder, and became standard practice in non-building-stone quarries.

However, quarry concerns were generally chary about employing these high explosives, not only for the reasons already noted in respect of black powder, but also, because they were largely unsuited to winning dimension stone (Greenwell & Elsdon 1913, 280).

In such quarries, high explosives were confined to careful removal of 'toes' or the 'butt' at the base of quarry faces. Initially, even for producing aggregates, such blasts were not favoured, as this was considered

to result in flaky rather than cube-shaped material. Even for cement and limemaking, they tended to produce too much fine stone, whereas lump stone was generally required in the 19th century.

The use of either black powder or high explosives is archaeologically significant, as they can display tell-tale features on quarry faces, which may infer a crude level of dating, or sequencing, of operations.

Until the interwar period, there were two main blasting techniques: springing involves a practice similar to today's method of making a limited number of near-vertical drill holes behind the face and charging them. In the pre-1939 period this was done with batches of black powder and high explosive, but simultaneously firing a small number of shots to drop the rock burden *en masse*. Most of the resulting rockfall simply broke up along natural joints and bedding planes.

However, most of the blasting was still carried out using manual (later mechanised, but still hand held) drilling and powder charging. Deep drilling of holes for face blasts was not widely practised until after the Second World war as most of the rock was required in large blocks (for cutting building stone) or as lumps for kiln feed.

One important method employed at the largest aggregate and industrial limestone quarries, was to use tunnel blasts (alternatively known as heading, chamber or mine blasts). In this case, a tunnel was driven into the face from the quarry floor. After a calculated distance, tunnels would then be made at right angles to the left and right and at the ends of which (sometimes, at intermediate points), chambers would be hollowed out. The chambers would be packed with many tonnes of explosive (usually black powder) then detonated, releasing in the largest cases 100,000 tons of rock. The whole process could take many months to prepare and the blast would often be a spectacular event for the community to witness. Tunnel blasts were certainly used in the 1880s and continued until at least 1949.

Undermining, comprised making a deep, horizontal (propped) cut into the base of a face and wedging out the rock with jacks. Small powder charges were then fired simultaneously, bringing the whole face down. With such methods, and even face blasts, secondary blasting to reduce large blocks to a suitable size for loading and - crushing in the quarry, was normal until the 1980s, when first drop balls and then mechanical 'peckers' offered safer solutions.

At the same time, these blasting techniques themselves changed to minimise the number of large blocks that would need further breaking. This was achieved by, for example, using customised explosives and multiple charged boreholes fired with millisecond delays to improve rock breakage.

Preparation for blasting, trimming quarry faces after blasts, and positioning small blast holes, was the responsibility of 'getters'. Most broken material was then lifted from the rock pile by 'fillers' hand loading carts or later, narrow gauge rail wagons (skips or tubs) drawn by horses, small locomotives, or rarely, men. Such quarries were described as 'hand filled' as opposed to mechanised (see Section 3.7.8).

Cranes were widely employed to lift blocks, or buckets, and skips of stone and to swing them into a works or onto trucks. From the mid-19th century, these were steam powered, then from the First World War petrol and diesel began to take over. Most cranes had ceased working by the 1980s.

Mechanization of filling and loading brought about considerable reductions in labour forces and a commensurate improvement in the, hitherto, abysmal safety record (HMIMQ 1950). It was largely accomplished in the 1950s (HM Inspector 1938-49), although some lime burners maintained that only hand filling could deliver the sizes of lumps able to meet specifications for kiln feed.

3.7.4 Minor extraction methods

Various unconventional methods of extraction were also employed, sometimes used over short periods.

Breakage, especially of inherently fissile sandstones and limestones (for roofing) by freeze/thaw processes, appears to have been recognised and applied in respect of Stonesfield 'slate' (Oxfordshire) from the late 16th century onwards (Aston 1974; Arkell 1947). It is still practised in both the Cotswolds and Collyweston in Northamptonshire, although by artificial refrigeration rather than natural frosting (Hughes 2003).

Exceptionally, fire setting to weaken large blocks was employed in the Clee Hills Quarries into the 1890s (Stanier 2000, 145).

In the 20th century, oxygen (thermal) lances, steam channelling, helicoidal (or helical) wire 'saws', chain saws, track-mounted circular saws and mechanical picks (originally designed for coal cutting) mounted on booms have all been used for extracting building stone, and air bags have been deployed to lift or prise apart large blocks of stone (Searle 1935; Greenwell & Elsdon 1913; Shadmon 1996). Liquid oxygen was used as a blasting medium (at least between the two World Wars (Searle 1935, 64).

Sand and gravel were generally hand dug with shovels but, in the 20th century, in addition to the conventional quarrying techniques, material has been extracted 'dry' by bucket-wheel excavators, scrapers, and 'wet' by suction and mechanical dredgers; draglines have been used in wet and dry operations (Searle 1923; Littler 1990; Cooper 2008).

3.7.5 Processing

Processing can be generally divided into two broad types, primary and secondary, defined as follows.

Primary methods include breaking stone down to the required size, block or crushed stone, and in some cases, washing or more elaborate separation.

Secondary activities include sawing (dimensioning), masonry finishing, coating, mixing with other materials, heating, drying; these are often grouped together as 'downstream' or 'added value' operations.

Primary processing

The main categories of primary processing in, adjacent to, or near the quarry, are:

- weathering – including: freezing over winter to break up stone slate block (in some areas known as logs) or allowing blocks of stone to drain out pore waters (so-called 'quarry sap'); in the process the stone becomes harder
- stone dressing (scappling blocks, bankers, splitting)
- stone breaking, crushing and screening (sizing), separating machinery (mostly in aggregate quarries)
- storage in bunkers/bins, stockyards
- lifting by cranes in the stone yard (usually smaller capacity cranes than in the quarry)
- power sources – human, animal, water (wheel or turbine), compressed air, steam, gas, oil, petrol, mixed fuel, rope and pulley, line shafting, hydraulics, electricity.

Breaking/crushing

Hand crushing by gangs was the norm until c.1900, and even fairly widespread until the Second World War. The practice, known as 'breaking' was often conducted on the quarry floor by 'breakers' or fillers assigned to



Figure 3.21 In order to split fissile limestones for roofing as here at Collyweston, Rutland, blocks ('logs') were traditionally left outside to over-winter using freeze-thaw processes.
© Greenwell and Elsdon

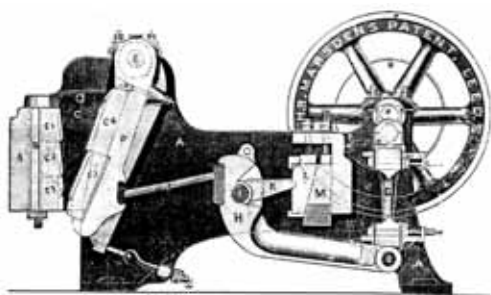


Figure 3.22 The three main types of crusher used today - jaw, gyratory and impact/hammer, were all developed by 1930. © Greenwell & Elsdon

blocks of the face, sometimes termed bargains or setts. Size selection within finer material took place at the first stage using open or close-tined forks, so that only material of a certain size was loaded. Final breakage down to usable size was carried out by men, women and children, using lump hammers and rings to gauge the size, in some cases as recently as the 1930s (*pers comm* R D Burton 2010). This was carried out at the quarry, by the road side or in special roadside bays as at Little Eaton (Derbyshire). Alternatively, size reduction was a task set for the inmates of poor houses, equipped with grids and hoppers through which stone had to pass. Also, as late as the 1930s in Charnwood, in Leicestershire, blocks of stone were delivered to local houses to be trimmed into road setts by the family; the product would be collected and payment made at the end of the week.

As far as mechanisation is concerned, the stone quarrying industry has always been a poor relation. Developments in processing materials such as metals and fuels have usually been adopted by UK stone quarries, many years after their earlier application in those 'high value' sectors; even in quarrying, most techniques were pioneered in North America. So, although Cornish rolls were employed in British mines by 1806 and later in America, and drop hammers and impact crushers had been patented by 1840, rock producers here did not follow suit until the late 19th century when reliable crushers, such as jaw, gyratory, and impact crushers came onto the market. By 1922, with the introduction of the Symons cone crusher, all the conventional stone crushing techniques now in use, had been developed (Mellor 1990).

Before 1848, George Stephenson at Groby Quarry, Leicestershire was experimenting with mechanical crushing. Only a few miles to the west, at Bardon Hill, it was recorded that viable roll crushers were introduced by 1858 and apparently produced crushed stone with little dust for c. 10d per ton compared with between 2s to 2s 6d per ton for manually crushed stone at that time

(Mountain 1860). Sir Robert Hadfield's 1882 invention of manganese steel, for tough applications such as crushers and excavator blades, resolved a number of long-standing shortcomings.

The other main process for aggregates (and most industrial uses) involves a series of iterative sorting processes by size (initially to remove dust and soil) starting with a grizzly (bars spaced apart) or feeder prior to the first crushing stage. Types of crushers were selected according to the rock concerned and product shape requirements. Where particularly high purity chemical stone quality is demanded, or in the case of most sand and gravel plants, the processing often also involves washing. Size sorting is now conventionally achieved by vibrating screens (large sieves) but a wide range of other methods have been applied; these include, from the mid- 19th century, the trommel, where (cylindrical) screens were common and, along with gravity and cyclone separation were used especially for sand and gravel. One novel method was to use heavy media separation (with ferro-silicon) to separate usable ragstone in Kent from sandy clay waste and (in Scotland), optical separation was applied to discriminate between white marble and the darker country rock waste. At a few sites, acid washing (leaching) and, or froth flotation was used to produce high purity sand, e.g. for producing colourless glass.

Secondary processing - blockstone

In producing dimensional building or decorative stone, processes usually begin with visual checking, marking up and scappling (cleaning off rough surfaces or general waste), a practice first used in Pre-Roman times, and usually applied in the quarry to minimise movement of unusable material. Today, rough faces might usually be removed by primary sawing (rather than scappling) to create smooth faced blocks or slabs, using large circular frame, gang or wire saws. Historically, sawing would have been carried out often by two people, using either a toothed saw (for softer stone), or for harder materials, a smooth-bladed saw to which grit, sand or later metal shot was added as an abrasive.

Mechanised stone saws were in use in mainland Europe before Britain. Water powered stone saws were recorded in Scotland in 1730 and at Ashford in Derbyshire for black 'marble' by 1748; an early windmill driven example is known at Southsea in Hampshire (Clifton-Taylor & Ireson 1986, 245). Steam saws were operating in Wirksworth in Derbyshire and in Derby by 1811 (Farey 1811). More powerful, faster and efficient frame saws were rapidly introduced as standard equipment shortly after their invention in the mid 19th century.

Final processing can include further cutting,



Figure 3.23 The former Hopton Wood Stone Firms' masonry workshop in Derbyshire, like Portland, produced thousands of military headstones following both World Wars. All trace of this and most other related buildings was removed in 2006 without record. © NSC collection

smoothing, lathe turning, profiling, polishing, buffing and surface treating, all of which had dedicated machinery until recently. Even traditional hand-letter and image cutting was mechanised (using pantographs) following the First World War, to meet the demand for a very large numbers of headstones. Nevertheless there was, and still is, a need for hand finishing or hand carving, albeit now often assisted by power tools.

These activities are the job of banker masons. Their products are then transferred to the construction site where fixer masons take over.

Secondary processing - granular materials

Downstream product manufacture, includes the following processes:

- lime burning and hydrating (in limekilns; hydrators, slaking pits/banks)
- for aggregates – further crushing and sizing (usually screening) utilising cone or various other crushers, vortexes, separators
- cement manufacture – crushing, blending, mixing in slurry tanks, pre-heaters, kilns, grinding plants
- concrete batching – mixing, batching
- mortar production – grinding, mixing, batching
- concrete products – mixing, batching, shaping, casting, curing, tensioning

- coated roadstone, asphalt/tar/pitch – mixing, blending, heating, batching
- mastic asphalt – mixing, batching, casting
- other ancillary activities might include gas production and tar distilling.

Hooley's original patent for 'tarmac' was lodged in 1902, but was not the first successful attempt to use coal tar. From the mid 19th century, coal tar had been used for mixing with gravel to pave city streets, but this practice came into more widespread use after 1900 with the exceptional growth in the use of rubber tyred road vehicles. Plants to mix roadstone, firstly with pitch, then coal-tar, and later with bitumen, began rather earlier. Initially this was in an attempt to synthesise asphalt (until then, imported in its natural form as rock asphalt from the late 18th century onwards variously from Europe and Trinidad). Tar needed to be distilled for road use to remove ammonical liquor and this was often carried out at tar/gas works in quarries. Refinery bitumen was first produced in the UK in 1920-1, but previously had been imported from Mexico. (Earle 1971, 1974; Ritchie 1999).

Ord and Maddison's patent stone breaking plant was available as early as 1871, and just after 1900 they introduced the first widely used paddle mixers for

tarred macadam. Other devices followed, including driers, and numerous plants were established by the mid 1920s. Operations began to be more automated, integrated into large batch-heater units.

Concrete batching plants were first introduced into the general UK market from Denmark in 1931 at Bedfont gravel pit in Middlesex. Well over a thousand plants have been established, both in quarries and on industrial sites, since then, (Cassell 1986). There were some variants of these mainstream activities, including those to produce mastic asphalt and mortar.

3.7.6 Internal transport

Early transport within quarries was either manual or by animal-power, with sleds (usually only over very short distances) or carts. There is also a tradition in Derbyshire, that completed millstones were tied in pairs and linked by axles like wheels, to be towed across moorland by draught animals (Barnatt & Smith 1997, 95). In the 19th and well into the 20th century, men or animals drew trucks on tracks from various points along the quarry faces, via sidings feeding a spine line, delivering to processing plants. From about 1820, the Haytor granite quarries in Devon used the system of flanged tracks made from granite setts to form a tramway, which is believed to be unique (Harris 2002). Locomotives (steam then petrol or diesel) began to take over at quarries from the 1890s. In 1927, at Waterlip Quarry, Mendip, an electric, automated rail system was established.

Steam shovels appear to have been relatively rare in the UK, compared with their use in railway construction or in quarries abroad although they were tried (rail mounted) at Tunstead in Derbyshire in the late 1920s.

In the 1930s, electrically powered track-laying excavators with trailing cables, began to be introduced at larger quarries such as New Frome (now Whatley) on Mendip and Tunstead in Derbyshire, and in 1933 they were used on Portland for clearing overburden (Anon 1933; Warland 1941; RD Burton *pers comm*; Thomas 2006). Reinforced converted road vehicles (often ex military) were used after the Second World War. Until the advent of reliable hydraulic systems in the late 1950s/early 60s, the excavators were wire controlled and, initially, the dumpers could only be discharged by hook systems mounted in crusher houses (Grimshaw 1985). By 1960, rail systems for internal transport had been largely replaced by trackless systems (excavators loading dumpers or conveyors) (Grimshaw 1985). For long or horizontal runs, belt conveyors are used; for short steeper transits, bucket conveyors or Archimedes screws might be employed. Slurries are usually

transferred by pipeline.

Quarry-specific, large capacity dumpers only came into wide-usage with the advent of the motorway construction programme from the late 1950s. Most of both the larger mobile and static plant was introduced or copied from the USA from metal ore and open-cast coal working. In much of the sand and gravel industry, mobile plant comprised heavy duty versions of agricultural vehicles, or in some cases barges or tramways.

3.7.7 External transport

This is largely outside the scope of this assessment and in terms of mode, parallels the changes already described under 'Internal Transport'. In summary quarries with access to navigable water prevailed at a regional scale (Alexander 1995), until the advent of rail, this being complemented, and in some places superseded, by petrol and diesel road transport (steam lorries making a brief contribution c.1910-35) by 1939 (Savery 1979). Large scale rail movements were resumed in the 1970s, but only at a few sites. One impact of the Second World War was the considerable loss of shipping capacity, which, with improved road networks, resulted in closure of some large coastal sites, especially in the Southwest, Channel Islands, and Wales (Thomas 2014). This enabled the three large inland aggregate producing areas to dominate to the present day.

3.7.8 Sources of power

Primary operations were and still are energy-hungry, and power in the early period (by 1870s) was provided by steam, for mechanical crushing and stone preparation (sawing, polishing), and before 1900 this was also a means of generating electricity and compressed air.

This situation continued in most instances until displaced by the use of gas, gas-oil and diesel driven generators from 1900 but mainly post 1920, then by petrol engines. Mains electricity was rare in the 1930s and often introduced as late as the 1950s.

Water power was used, as at Clee Hill in the 1880s, and for crushing at Hapsford (near Frome, Somerset) in the 1890s. Water wheels provided power for hauling at Delabole slate quarry (Buckley 2005, 202), and where pumping was necessary in deep quarries, such as the Meldon (Devon) limestone quarries (Fletcher et al. 1997a).

3.7.9 Lime production

Production of lime involves heating limestone (including chalk or dolostone) usually in some form of coal-fired

kiln. Styles of 'kiln' have varied considerably over time, starting with:

1. Sod and pye kilns which are usually pre-1830 (Leach 1995; Barnatt & Dickenson 2004; Johnson 2010a).
2. Between 1750 and 1914 stone-built kilns were in use, usually hillside intermittent 'flare' and continuous types (Searle 1935; Williams 2004; Johnson 2010a).
3. From 1864 until the c. 1950s, batch ring, oval, elliptical, rectangular types were developed (e.g. Hoffmann patented 1857; De Witt) (Knibbs 1924; Eckel 1922; Searle 1935; Johnson 2010a).
4. From late 19th century to the present, shaft, vertical, often metal clad kilns were the norm (there were numerous variations, including Wests, 'Patent', Priest, tunnel, and many European designs - currently mainly Maerz) (Knibbs 1924; Eckel 1922; Searle 1935; Oates 2008; Boynton 1980).
5. From 1893 rotary and in 1960s-80s rotating hearth (Calcimatic) kilns.

Kilns currently operate at 800 to 900° but in the past some kilns ran up to 1200° (Searle 1935). Lime was raked out (or discharged by conveyor) and sorted by hand in covered attached sheds. It might then be crushed and screened to sizes required and bagged or barrelled. Some lime would then be hydrated by addition of water or steam, to various degrees ranging from powder, to putty to milk of lime. A further process might involve mixing lime, water and sand to make mortar; this was normally undertaken on construction sites by one person but there are examples in the past of production (as today) on more of an industrial scale (Cadman & Audouy 1990).

3.7.10 Cement production

The evolution of lime to Portland cement is covered in Section 3.2.5.

Preparation of kiln feed (either hard limestone or chalk with clay/mudstone/shale/clay slurry) involves crushing, washing, removal of flint or chert (sold separately), screening and blending. The need to control raw materials is paramount and regular testing (now automated) has always been an important consideration. In most cases, raw materials are transported from quarries to the works, by the means already described, but in the Southeast, wash mills at quarries sometimes sent slurry to the works by pipeline. This practice still continues but via a long distance pipeline from Kensworth (Bedfordshire), 92km to Rugby Works (Warwickshire), where the local feedstock is insufficiently calcareous.

Early bottle shaped, and other vertical kilns, were the norm before 1900, but a great variety of others



Figure 3.24 Compared with other mineral workings, water power was rarely used to crush stone. Hapsford Mill, Frome, Somerset operating c. 1900 was an exception. © Ian Thomas

inherited from the lime industry were also applied. (Butler 1913; Francis 1977; Cement kilns 2012')

Ransome developed the first rotating kiln at Arlesley in Bedfordshire in 1877 (Stanley 1979). Although this greatly increased the efficiency and reduced production costs, early versions were unsuccessful. Only when rotary kilns were reintroduced from the USA in 1903, did they begin to displace vertical kilns. Rotary processing has become the staple machinery of the industry to the present day.

Up until the 1970s, 'wet processes' dominated English manufacture. These involved producing a slurry mix of limestone and clay, for which chalk was an ideal feedstock. The fuel crisis in that decade, resulted in a change to more semi-dry and dry process works.

To increase energy efficiency, many devices have been developed to use waste heat to dry and pre-heat the kiln feed, and filters and precipitators have been added to control dust emissions. The kiln product is a hard clinker which has to be ground to a powder (usually in ball mills) and blended with ground gypsum to control cement setting times. The final product used to be barrelled but is now bagged or delivered in bulk.

3.8 Field archaeology

3.8.1 Bulk minerals typology

A combination of geology, topography and technology will usually have determined the morphology of a

site worked for stone. However, the form may not necessarily be apparent decades, or centuries, after the site has been abandoned. In particular, waste tips from later phases and current vegetation may obscure the original working pattern. Typology or evidence of tool usage are rarely a good guide to period of activity, as techniques changed little over the centuries up to 1900.

As a framework for stone studies, Peacock (1998, 9-12) suggested a sequence of stages from assessment of the resource through to end use and decay. This is summarised below, augmented with the addition of (5) and (9) to complete the cycle and to provide amplification, mainly in order to extend the concept beyond the medieval period :

1. Raw material assessment – geological resource, character and composition.
2. Resource assessment – availability, location vis a vis transport and markets, workability.
3. Decision – to quarry or not to quarry.
4. Process
 - planning of extraction
 - method of extraction
 - initial processing – ‘primary processing’
 - finishing – ‘secondary processing’.
5. Transport and delivery.
6. Assembly – installation in finished state.
7. Use of product – deterioration in use.
8. Decay after use – weathering/ breakage/biological colonisation.
9. Re-use and iteration of (3-8) above.

Peacock’s analysis focuses on the evidence of human interventions as part of a continuum, but he mostly confines his analysis to medieval and earlier periods. In terms of archaeology, activities 4-8 are the most evident, although 1-3 are always pre-requisites.

3.8.2 Extractive sites

The only reasonably comprehensive presentation of quarry-related archaeology is that by Stanier (2000). Most of the lists below are based to a lesser or greater degree on his work, augmented and exemplified by the present author.

Topographic setting

- Hillside (often called ‘daleside’) following a deposit into a hillside – perhaps extending an existing cliff or widening a valley side, for example in Miller’s and Great Rocks Dales, Derbyshire; Teign Valley, Devon; Batts Combe, Somerset.
- Hilltop/crown – skimming off the top of a hill – often an outlier such as Ham Hill in Somerset;



Figure 3.25 Many traditional, smaller kilns have been studied and frequently preserved. Apart from a few classic Hoffmanns, almost none of the great variety of pre WWII industrial designs remain. These De Witt Kilns at Amberley Chalk Pits Museum, Sussex are exceptional. © Ian Thomas

Clee Hill in Shropshire; gravel working of some high level glacial deposits.

- Scarp edge – extending a natural cliff feature towards a dip slope, such as Millstone Edge and Stanage west of Sheffield; Wenlock Edge in Shropshire; Leckhampton Hill in Gloucestershire; Whin Sill in Co. Durham/ Northumberland.
- Plateau or very gently dipping land – these may be very shallow, or of considerable depth in massive rock deposits as with the Cotswold dip slopes and many former chalk workings.
- Dome incision – excavation of a massive deposit from the crest of a hill downwards, as seen at Mountsorrel, Croft and Cliffe Hill in Leicestershire.
- Glory-hole – a variant on hillside and - plateau or dome incision, is to create a narrow entrance (or even a tunnel) from a low point, to extract stone from a neighbouring high point or plateau. Examples include Chelmscombe in Somerset; Monkey Hole, Derbyshire; Criggion, Shropshire/ Powys; Giggleswick in the Yorkshire Dales.
- Valley floor or valley terrace working (most fluvial sand and gravel workings).
- Grooved – following a long, narrow (vein-like) deposit across a broad landscape, for example, the Cleveland Dyke in the North Yorkshire Moors and slate from Honister in Cumbria.
- ‘Valued’ beds below, or inter-bedded with, substantial overburden, such as bedded Liassic ironstones and limestones, Kentish ragstone, and many flint and chert operations.

Mining is often an underground extension of these operations.

Operational style or type

- Gathering scatter of 'loose' surface stones, including moorstones in granite areas, such as Dartmoor in Devon; sarsens; limestone pavement collecting; and boulder breakage on the gritstone moors of the Peak District; extraction of glacial limestone erratics in W Yorks. Probably the most extensive activity of this type (over millenia) was stone clearing of fields and use of the rubble produced for field walls or local vernacular buildings.
- Shallow (under c.7m), but often laterally extensive, open pit (reaching down a bed or two; such as 'hills and holes/hollows', of any period), such as Barnack in Cambridgeshire and stone and slate at Harden Clough in W Yorks.
- Small quarry (face over c.7m and less than 30m; the most historically common type of quarry, but may be infilled and therefore difficult to detect). These may or may not be benched.
- Large quarry (defined by depth and/or area; includes most rock aggregate units; these will often be benched for access and safety reasons, particularly if parts have been operational since the 1970s).
- Narrow cut – following a narrow outcrop e.g. Cleveland Dyke on Moors near Whitby; some slate and limestone operations in Cumbria.
- Underground mine via adit or shaft (in some places known as 'quarries' see Section 3.1.4) (usually following a specific bed with specific characteristics or concentration of nodules). Examples include Bath stone; Chilmark; Carnglaze slate; Reigate stone.
- Dredging operation – wet sand/gravel working in rivers, estuaries, beaches and offshore, including the Dee and Severn estuaries.
- Progressively advanced/rolling reinstatement – thin beds accompanied by substantial waste. In the past often hand operated using high planked barrow-ways, superseded by draglines of the type once used at many Liassic Limestone quarries in the Midlands,

Quarrying techniques

- Removal of overburden or 'ridding' (evidence is in waste tips and at the quarry face top).
- Surface cutting (evidence includes wedge pits, roughouts, voids).
- Waste disposal - overburden and quarried waste (evidence in stack, bench, finger dump or cliff-tipping sites).
- Extraction at the quarry or mine face, by hand



Figure 3.26 Geology plays a vital role in defining quarry format. Extraction of basaltic andesite along the Cleveland Dyke is an extreme example. The feature runs for c.370km from Mull almost to Whitby. Workings crossing the North Yorkshire Moors are typically 22m wide and 30m deep as at Coatham Stob. British Geological Survey CP15/061 © NERC 2015 All rights reserved

or mechanised (see Section 3.7.3-4) (evidence includes tool-specific marks, low- or high-explosive fractures, drill holes of varying diameters, face tunnels preparatory to tunnel blasting).

- Secondary working, or breaking, of extracted material (evidence includes split large blocks, accumulations of fines *in situ* in quarry and on tips).
- Lifting by jack, sheer-legs, crab, winch, wire dragged skip, dragline or crane from the face, onto mainly internal transport, crane or derrick, or if removed, the crane base and platform, anchor stones/blocks or metal strong points/rings).

Most of the extraction methods leave behind characteristic 'tool' marks in rock faces, although simple levering out usually provides few, or no, signs (except where very little weathering has occurred subsequently). However, the longevity of many techniques, means that dating is usually problematic. Wedge pits or grooves, into which wedges were inserted, were used to prise apart blocks of stone at right angles to the bedding plane, effectively creating artificial joints (Stanier 2000, 23).

Quarries were often worked in 'lots' or 'sets', each by separate gangs of men bound by a 'bargain'. This practice, which began in medieval times, was still operated into the early post-Second World War period at some sites. This means of working may be reflected in irregular patterns defining such areas within a quarry face.

Quarry blast holes, or shot holes, may remain at building stone quarries. In shallow workings these are seen as numerous half section smooth holes, c.25-30mm diameter up to c.1m long, ending in a black discolouration (powder imprint) with little or no evident fracturing. Where high explosives were used, the drill holes are near vertical, much broader (30-100mm plus) and up to 5m long; they terminate in fractured rock around the position of the charge, leaving what Raistrick (1972) termed, 'star' patterns.

Explosives magazines and detonator stores, have often survived long after all other buildings have been effaced.

Waste and unsold or abandoned products

Waste material is almost always generated in quarries, and the style of deposit can often tell us as much about the operation as most of the rest of the site features. Indeed, it might represent almost the only clue to the former activity. It can indicate the methods of extraction, movement, processing. The shape of the tips and relative sizes of the discarded material can suggest the period and duration of working, and whether the output was a bulk one or for more specialist products with higher levels of waste. This can be seen in terms of the scale of waste and the relationship to the quarry void and processing carried out.

Roughed-out querns, millstones and pulpstones may be found *in situ* or in detached blocks and give the key to working methods or choice of beds exploited. Fluctuation in trade or flaws may offer reasons for abandonment and can give a clue to the effort and skills required.

Where a progressive advance and backfill has been employed, such as using high plank barrow ways or draglines, little evidence may remain on the surface, especially where the land has been reinstated, regraded and planted.



Figure 3.27 Examination of discards and waste may constitute vital evidence of a site's former activities. – quarry near Glossop. © Ian Thomas

Under-burnt and over-burnt material in lime waste can indicate working temperatures of a kiln. Fragments of non-fossil fuels may provide a means of determining approximate operational dates. The presence of waste heaps, comprising burnt coal and lime dust, is a possible indicator of commercial lime production, whereas at field kilns everything was removed for spreading on the fields.

'Handfilled' limestone quarries can sometimes be differentiated from those with mechanised loading by the dry nature of, or in contrast, ponding on, the quarry floor. Natural drainage is less likely to have been impeded in hand loading than by the activities of machine movements, which generate more fines, filling holes and cracks/joints. The size, shape, mix and disposition of waste may also differentiate the two methods of working.

The shape of tips is usually an indicator as to the tipping method; finger dumps are the result of tipping wagons, and conical 'sky' tips were produced by overhead rope-bucket lines, rope-hauled inclined rail systems or conveyors.

Slurry pits, tanks and ponds are usually associated with settling lagoons, which were required where washing is involved.

The inter-relationships between waste deposits and building or machinery foundations may be fundamental to the interpretation of a site, and in particular, the sequence of processing.

3.8.3 Processing

For some of the reasons given at the beginning of Section 3.9, there may be relatively little evidence of processing at ground level.

Primary processing

For sites where building stone was produced, stone stock yards may still carry residual cut stone, and the walls of banker masons' dressing sheds, booths or cabins, discarded hand tools, or saw blades, may be found.

Until the Second World War, most aggregates processing plant (particularly for sand and gravel) was housed in timber structures, which after the First World War were generally clad, if at all, in corrugated iron. In general, only the larger well established plants were of brick and stone. After the Second World War, steel framing and cladding became very common but metalwork has typically been subsequently removed for scrap or for reuse elsewhere. The main remaining features for primary aggregates processing tend to be the durable hard-standings, concrete machine bases, often with bolting points, severed stanchions and chutes, and in some cases, concrete or brick block storage bins, silos and tanks. Slurry settling tanks or ponds and



Figure 3.28 Timber and corrugated iron plant buildings at Cliffe Hill, Leics, typical of the period up to the 1970s. Like their more recent counterparts, planners will normally insist on complete removal on closure. © NSC collection

drainage channels may also remain *in situ*. Exceptionally, larger plant items, or their key parts at remote sites may have survived.

Secondary processing

Most of the remnant types referred to in primary processing also apply to secondary processing. However, certain categories of activity are also reflected better on the ground, the main group being lime kilns, especially those built prior to 1945 in stone or brick. Few, if any, disused metal kilns have survived. Most other forms of secondary processing, such as concrete batching, concrete product, or coated roadstone, mastic asphalt and mortar mixing, are even more poorly represented (see Section 3.9). Discarded ingredients or products such as tar, bitumen, imported sand or coarse aggregate, cements, reinforcing bar, concrete or concrete products, may also be telltale signs of the type and vintage of activity.

3.8.4 Movement of materials (mainly internal, see Section 3.7.8)

Associated features include :

- roads, trackways, wheel grooves within the quarry
- tramways, from the face to the processing areas and waste tips (evidence may be the tramway course with sleeper blocks, sleepers, rails, inclines, winding drums, bridges and tunnels, cuttings, embankments)
- loading platforms and gauges (for roadways and tramways)

- tramways within processing areas and marshalling yards
- wharves, jetties, docks
- stables, engine sheds, water tanks, balancing systems, fuel stores, tanks, sand boxes
- transport from the site (track, road, tramway, railway, barge ship).
- canals, canal extensions, loading quays
- abandoned mobile plant.

3.8.5 Sources of power (see Section 3.7.8)

Motive power: may be human, animal, rope and pulley, counterbalanced weights, water, steam, diesel, gas-oil, compressed air, petrol, hydraulics, electricity.

Associated features include:

- fuel stores
- boilers
- fuel lines
- steam or compressed air lines
- hydraulic rams
- pulleys, ropes and line shafts
- water tanks, pipework
- engine sheds
- stables
- power lines/trailing cables
- generators
- gas/gas-oil engines.

3.8.6 Infrastructure

Ancillary buildings in and around a quarry may include:

- blacksmiths' shops
- powder houses or magazines
- stone dressing huts and shelters
- masons' and sett makers bankers
- blast shelters
- workers shelters, mess rooms, changing rooms, crib houses or grub huts
- machinery houses (engine, compressor, generator, boiler)
- quarry offices, weigh-bridges
- other support activities – repair shops, stores, medical/first aid and rescue stations
- housing - managers', foremen's, workers', barracks, cottages, terraces, villages
- community facilities – company shops, chapels, schools, villages, hospitals, club rooms, sports provision.

3.8.7 Chronology of stone use

Information on the chronological development of the industry is given in more detail in Section 3.3 and on

finds in Section 3.9. Only the main forms seen in the field are summarised here. Prehistoric stone implements are discussed elsewhere (Section 2).

Prehistoric stone structures (see Section 3.2.2)

Precise stone sourcing has usually been incidental to most research on this class of monuments. Stones employed were often from residual deposits (e.g. sarsens), or erratic, or slabs separated from bedrock by surface weathering, and quarrying is scarcely present as a recognisable activity. However, some examples (including some *in situ* material) still retain evidence of 'processing' in the form of wedge pits, dressing waste, etc. (Stanier 2000). Furthermore, some of the techniques involved in extraction (wedging and levering), in shaping (scappling) and in transport (on sledges or rollers) were refined and employed later in conventional quarrying over several millennia. Stanier (2000) records these gathering practices as still widespread in the Southwest granite areas, well into 19th century.

Bronze and Iron Ages

Portable stone artefacts formed a major component of the material culture in the later prehistoric period, including flint/chert tools (see Section 2.10), metallurgical uses (see Section 3.2.3), net sinkers, loomweights and querns (see Section 2.14). With the exception of quern manufacture, few of these early applications appear to have been sufficient to result in quarries which can be firmly identified today.

Roman

Hayward (2009) demonstrates that, even during the 1st century AD, the Romans were exploiting the main freestone sources of the Jurassic Stone Belt as far north as Lincoln. But in terms of form and scale, just as in the earlier case of winning material for stone implements, it was only in exceptional circumstances (such as Purbeck in Dorset) that one might class Roman stone activities as an 'industry' (Pearson 2006, 11).

Apart from specific inscriptions and undateable tool marks (plug and feather, or pick), very little archaeological evidence of Roman stone extraction survives (Pearson 2006). However, occasionally the characteristics of specific types of stone made them particularly suitable for some uses and quarries might be exploited, sometimes for longer periods. In Southwest England, Beacon Hill near Shepton Mallet (Somerset HER UID 15485), is a source of Devonian sandstones where extensive remains of quarrying, in the form of bell-shaped pits and vertical rock faces, have been identified. The demand for such types of stone could overcome the economic constraints on transport. This was the case with the slates of South Devon which were exploited in the later Roman period to supply

roofing material for Exeter (Holbrook & Bidwell 1991).

Similarly, the exploitation of the limestones of the Southwest region appears to have been important. These included Bath stone, and many other oolitic limestones of the Cotswolds, and Purbeck stone, the last being transported significant distances for use in inscriptions. Although the products of such activity are widespread (see Blagg (1990) for example), and its economic significance must have been high, little is known about the archaeology of the extraction of building stone.

At Dundry Down in Avon there are Roman stone quarries, and at Beer on the Southeast Devon coast, there are limestone quarries showing evidence of Roman working (in the form of an early adit) (Edwards 2011, 91). Other sources of roofing slate were the Precambrian Swithland Slate from Roman quarries in Leicestershire, (Brittan and Ramsey 2007) and Stonesfield Slate from Oxfordshire (Aston 1974) was also first quarried during the Roman Period; the latter and many other sources were used as roofing slates during the construction of Cotswold villas.

Although there is no firm site evidence for pre-Roman production of lime, it was clearly an important and much-used commodity in Roman times and the first lime kilns were operational very soon after 44 AD (Eve & Stead 1998), and examples have now been excavated (Johnson 2010a, 11).

Medieval

The Saxon stone industry had become well established in the south of England by the 10th to 11th centuries (Jope 1964), with most of the key building stone resources known today being exploited at a limited number of locations. As already recorded, there was also a widely practiced tendency to recycle Roman building materials.

The Normans, and their successors, greatly expanded building stone extraction for ecclesiastical and military purposes. For the first time, documentary, geological, petrological, transport, and site evidence can be reliably deployed to tie buildings to specific quarry sources on a reasonably wide scale (Knoop & Jones 1938, 1967).

Some architectural detailing reached a high point just before the dissolution of the monasteries, epitomised in the fan vaulting of Bath Abbey and the Royal Chapels at Windsor and Cambridge. With it came increased knowledge of stone quality and careful selection at the quarry face. However, in the quarries themselves almost no clues remain to demonstrate such finessing of extraction, apart from in exceptional circumstances, such as when an identifiable band is pursued underground by mining. In such instances, the detailed



Figure 3.29 David Peacock’s discovery of Lodsworth Iron Age/Roman quern pits (West Sussex) offers a textbook case, combining deductions based on geology/petrology, archaeology (on/off-site) typology and documentary evidence. After Peacock 1997 modified by Pearson

evidence on working faces can be considerable when compared with contemporaneous surface extraction.

Post-medieval to 1750

Most of the post-medieval developments have already been reported chronologically. In summary, almost all quarrying and stone processing techniques changed very little from pre-medieval times until at least the mid-18th century. Hand tools exhibited negligible development in terms of form. As a corollary, tool marks on quarry faces and shaped blocks also demonstrated little noticeable variation.

In this context, very often it is archival material and not field evidence, that provides the best chronological data for a given site, but even that must be applied with caution on account of the frequent practice of sites being re-opened and closed, often over centuries and usually without record.

From 1750

By far the greatest developments came in this period, including the growing use of black powder, especially after 1800; the replacement of human and animal power by steam, oil, petrol, water power and electricity followed. Mechanisation of processing usually preceded the application of power to extraction. Loading and internal transport followed but was only more or less universal as late as the early 1950s. In many building stone quarries, mechanisation tended to come even later for quarry activities than processing.

Hand tools changed in composition with the introduction of special steel alloys (e.g. manganese and tungsten), mainly from the late 19th century onwards, but there was still very little development of tool form and style, until the advent of mechanisation.

3.9 Archaeological recording

3.9.1 Overview of research

Parson's (1990a) opinion, that archaeological coverage of the bulk minerals is far less satisfactory than for other sectors of the extractive industry, such as coal and the metallic ores, is almost self evident. Even in comparison with, for example, the slate industry in Wales, there appear to be no areas or sub-sectors within bulk minerals in England (with the notable exception of prehistoric flint), to have been researched in as much detail. Whereas the situation was further scrutinised in the 1990s, little appears to have been done since 2000 to remedy the situation.

The English Heritage report, *Exploring Our Past* (English Heritage 1991, 42), identified stone as an archaeological problem area. The authors claimed that the extraction, manufacture and distribution of stone artefacts remains poorly understood, whether these are the cutting tools of prehistory, such as axes and knives, or the grinding implements such as hones and querns. The same document recommended a programme 'to identify basic recording standards, guidelines for processing, shortcomings in regional and local sequences and themes for potential study' (English Heritage 1991, 51). As a result, English Heritage commissioned Prof David Peacock, University of Southampton, to prepare the report *The Archaeology of Stone* (Peacock 1998), covering stone other than flint. His brief was to examine retention and processing



Figure 3.30 Tunstead Quarry, Buxton replaced up to twenty other operations between the wars and continues today as a technological leader. The transition between hand- (foreground) and machine-filling (distance) is shown here in 1948. Although change has resulted in physical loss, almost every adaption has been recorded in an extensive photographic archive. © NSC collection

policies, to evaluate the needs of stone identification and provenancing, and to examine ways of recording technological traces of stone working or use. Peacock's work reflected the situation in the mid 1990s. A key finding indicated that the main concern was with building materials (and in particular, the sheer volume of material), rather than, as might have been anticipated, with axes, hones or querns. He noted that despite stone ranking high in importance among artefacts, stone often has a low priority in archaeological research; analysis is frequently undertaken by non-specialist staff, and many stone specialists come from a geological rather than archaeological background. He goes on to assert that stone has great potential to help understand economic and social issues of the past (Peacock 1998, viii).

Where stone has been considered in archaeology, by far the greatest contribution to knowledge has been in the identification of artefacts, building and monumental materials. This is often accompanied by a tentative indication of general location or type of source, based largely on petrology. So the process has tended to rely heavily upon geological judgements and knowledge of geological outcrops at the time. In many instances this rests on an interpretation of geological baseline information by non-geologists. By comparison, very little attention has been paid to thorough examination of the precise origins or the methods by which the materials were obtained from the ground.

Peacock (1998) provided a useful account of research in respect of stone, but focussed mainly on recording activities up to the end of the medieval period. He studied references to stone finds in a selected cross-section of specialist journals. In 98% of the 196 excavation reports covering 'all chronological periods', stone had been encountered. He also considered that the paucity of specialist geological input in the site investigation reports was 'perhaps the most disturbing aspect', as only in 3% was there specialist geological verification. However, almost all the references reviewed, related to portable artefacts, building materials or the geological context of the archaeological site; in all these reports, apparently, there is not a single specific mention of quarry sites in the related analysis.

Parsons (1990a, 13), referring to Roman and early medieval Britain, concludes that the prime need is for secure petrological determinations based on scientific observations, rather than on the subjective impressions that have tended to bedevil the subject in the past. He then expands his comment to apply to all periods. In this respect also, Pearson (2006, 12) welcomes greater collaboration between archaeologists and geologists.

The MPP3 report (Cranstone et al. 1999) is also indicative, but appears to understate the situation. They



Figure 3.31 Barnack Quarries, Rutland were some of the most important in medieval eastern England. They are now a highly protected nature reserve, but their considerable historical significance is virtually unrecognised. © Ian Thomas

investigated 315 sub-site records for 309 sites and concluded by noting that:

- the coverage of Roman quarry sites is adequate
- the medieval period, while well covered historically, is under-represented in terms of field evidence
- in the post-medieval and modern periods, the geological spread is good, some forms of quarrying (glory hole, surface types, loose deposit) are insufficiently covered
- explosives and blasting representation could be improved
- of the important end-use groups, most forms of by product category were poor, and aggregates, fluxes (outside the Midlands) were scarcely exemplified and no asphalt sites were recorded.

What are the main factors behind the shortcomings, not only as noted by Parsons (1990a) and Peacock (1998) for pre 1540, but for recording subsequent bulk mineral extraction?

The issues influencing or inhibiting archaeological investigation of quarries are:

- extensive scale of operations - consequent effort in cost and time implications for recording with perceived limited return
- removal and loss of evidence or access as a result of:
 - later extractive activities (possibly continued intermittently for centuries)

- clearance required by planning authorities and landowners
- clearance for scrap or re-use elsewhere
- flooding
- vegetation
- biologically protected sites
- tipping – quarry waste, landfill
- redevelopment ('brownfield land')
- reclamation schemes for derelict land
- infilling of underground workings
- generation of toxic or inflammable gases and liquids
- health and safety considerations
- company health and safety policies regarding quarry access and underground exploration
- lack of variation of extractive techniques can make verification recognition of earlier operations problematic
- field evidence perceived as not sufficiently interesting or inspiring to motivate investigation.
- preponderance of 20th-century activities within the total population of bulk minerals sites and a common misconception that these are not worthy of archaeological consideration.
- where quarries are accessible for scrap merchants, equipment seldom survives; often only machinery bases and foundations may remain. Most removable equipment is taken off site at or shortly after closure by the operators
- disconnect between archaeology centred on artefacts, buildings, structures and their source materials/ sites

- degrading of quarry face detail through weathering
- failure to follow through from historical records to field verification
- failure by field investigators to differentiate between a natural cliffs, crags and quarries
- a lack of comprehensive or systematic corpus of quarry historical records as a starting point
- widespread lack of official recognition/ appreciation of the significance of sites. i.e. 'Heritage Quarries' (Thomas *in press*).

More specifically, there are few if any major categories of development other than quarrying, mining and their downstream processing activities, to which planners since the late 1940s, have applied almost universally, the rule that all evidence must be completely removed and land restored as far as feasible to the *status quo ante*.

3.9.2 Modern assessment

The analysis in the Monument Protection Programme (MPP) Step 3 Report – Quarrying (Cranstone & Newman 1999, 10), is particularly telling. Prehistoric flint operations were intentionally excluded as covered elsewhere. Based on their work in 1996-99, out of over 300 sites surveyed, 14 sites were graded '+++'. These were as follows (site ref numbers used in the report are in brackets):

Roman (Cumbria 11,13) River Gelt; Coomb Crag
Medieval (North Yorks 12, Isle of Wight 1) Rievaulx; Binstead
Post - Medieval Slate (Cumbria 5, 7, 15) Hodge Close; High Quarry; Coniston Old Man
Underground Stone Mines (Devon 9, Surrey 6) Beer; Chaldon Firestone
Flint Mills (Staffordshire 1,2) Etruscan Bone, Cheddleton
Post - Medieval hushed quarry (Lancs 2) Sheddon Clough
Jet Workings (North Yorks 3) Carlton Bank
Post Medieval Landscape (Shropshire 1) Llanymynech and Pant.

Out of several tens of thousands of bulk minerals quarries and mines operational in England since about 1800, only one example has been put forward as of national importance and thus worthy of designation. This was at Llanymynech (half of which, ironically, lies in Wales, the other half in Shropshire). These 14 sites inadequately represent this heritage resource, particularly the mass of quarrying activity over the last two centuries; the two processing mills listed are distant

from their primary sources; jet and hushing are only marginal activities and two are underground operations.

According to the MPP Quarrying Industry Report (Cranstone & Newman 1999, 10) 'the selection of sites on the basis of historical association' was revealed 'to be unreliable in relation to producing sites that have good surviving physical features of scheduable quality'. For the reasons given earlier, this probably largely holds true, but in the absence of comprehensive historical accounts and systematic follow-up in the field at present, this must be a subjective judgement.

3.9.3 Summary of research coverage

(excluding prehistoric flint mining, for which see Section 2)

Certain subjects or areas, indeed in some cases, 'niche interests' have been well researched. However, most of the archaeological research conducted has been artefact-led, while work on quarries themselves has been, at best marginal. There are exceptions, as with limekilns (but more is needed on the quarries themselves), querns and millstones, prehistoric flint mines and specific axe 'factories'.

For some key bulk minerals, archaeological fieldwork is almost entirely absent. The situation in respect of the aggregates industry is particularly acute, a considerable indictment when taken in the context of the several million pounds dispensed annually until 2011, from the Aggregates Levy Sustainability Fund on archaeological support, and the even greater sums gained from the industry in pre-extraction fieldwork via planning conditions.

Bronze and Iron Ages

Stone was being employed for 'civil structures'. For example the Shardlow Bronze Age log boat contained five shaped blocks of Bromsgrove sandstone extracted a short distance upstream along the Trent at King's Mills in Leicestershire; the sandstone is assumed to be for use in a causeway across the Trent (Hull & Salisbury 1999; Garton 2001).

Of the materials required for the production of metals (see Section 3.2.3), only honestones appear to

Table 3.5 Archaeological coverage by period

Period	Poor	Medium	Good
Prehistoric			xxx
Roman	xx	x	
Med (early)	xxx		
Med (late)	xx	x	
Modern (early)	xxx		
Post-1750	x	x	x



Figure 3.32 Limestone has been extracted around Clipsham, Rutland, since Roman times. Largely as a result of its robust quality and the closure of other quarries, it is still one of most used Jurassic stones. © Ian Thomas

have been studied in much detail. This is despite much analytical work having been conducted upon historic metal objects as well as at some smelting and smithing sites of the Bronze and Iron Ages (Bayley et al. 2008)

Querns have been perhaps the most studied subgroup of stone artefacts, starting with Curwen's general overview of the topic in 1937 and 1941. They have since been reported by Peacock (1987), concerning Lodsworth stone in Sussex; Saunders (1998/9), who investigated Old Red Sandstone in the Forest of Dean; Hayes Hemingway and Spratt (1980), who studied the bee-hive querns in Northeast Yorkshire; Keller (1989a) looked at the querns of Folkestone in Kent. A quern survey was carried out and reported by The Yorkshire Archaeological Society in 2006 and W S Penn surveyed Kent querns in 1966 (Keller 1989b).

Cranstone and Newman (1999) identify only the quern sites at Wharnccliffe, near Sheffield (Iron age/Roman) and Pen Pits in Somerset, as verifiable Pre-Roman quarry sites (excepting stone/flint implements), together with Binstead limestone quarries (essentially a medieval site) on the Isle of Wight. The Wharnccliffe site has been explored by Wright (1988) and more recently by Pearson (2000).

Roman

Williams (1971a, 1971b), writing about southern England, commented on the shortcomings of the existing academic literature on Roman stone sourcing and quarrying, and concluded that there was insufficient data available for a definitive study. He noted the comparative lack of attention given to quarries when

contrasted with that of their key product, namely Roman architecture.

Pearson has attempted to remedy this situation with the benefit of 35 subsequent years of research in respect of individual quarries, as well as both a specific and more holistic approach to investigation of buildings. He emphasises that it is still very much a case of 'work in progress' hampered both by lack of information and unreliable identification (Pearson 2006, 9).

Research efforts have tended towards the exotic, prestigious or distinctive stone types, which, ironically, are often more easily identifiable (notably Purbeck 'Marble'), while less attention has been paid to locally-derived building stones. Considerable volumes of stone were used in road building and maintenance (see Section 3.2) but no conclusive evidence appears to have been recorded of related extraction.

By far the largest volume of research for the period stems from work on individual, or groups, of buildings with associated, or suggested, sources of the stone. Usually, the stone is tracked to a rock type, sometimes a specific geological formation, but seldom to a quarry site. However, in a reasonable number of instances, a cluster of possible extractive sites or generic zones rather than sites, are referred to; for example, Bath, Cirencester (Wacher 1995, 345), York (Buckland PC 1988), or the villas of the North Gloucestershire Cotswolds and Silchester in Hampshire (Sellwood 1984).

Only exceptionally have actual Roman quarry sites been investigated, or indeed specifically located, let alone excavated. Foremost of the exceptions is the group of half a dozen sites associated with Hadrian's Wall at Crowdundle, Wetherall, Coomb Crag, Pigeon Crag, River Gelt – all in Cumbria – and Queen's Crag in Northumberland. Their identification is based on the presence of inscriptions (Pearson 2006). At Handbridge in Cheshire, a shrine to Minerva remains (Thompson 1965).

Cranstone et al. (1999) list 15 'Roman' quarries. Those associated with Hadrian's Wall account for just over half; almost all the others produced limestone (including Ham Hill and Dundry in Somerset, Beer in Devon, Tisbury in Wiltshire and Barnack in Cambridgeshire – all later to become classic freestone sources), or slate (Swithland in Leicestershire) for many centuries thereafter. A further nine Roman quarries, less substantiated, were identified in an earlier edition of the MPP process. More recently, Pearson (Pearson 2006) has published a wider ranging analysis of the Roman stone industry (which rests heavily upon Blagg's earlier work of 1976 & 1990). Both Blagg and Pearson carry a useful list of references. Taking these and other reports, probably forty specific or close clusters of Roman quarry sites, have now been defined, heavily

concentrated on Hadrian's Wall and the Jurassic Stone Belt (the latter being particularly favoured as ideal terrain for villa-based estates). Other putative Roman quarry sites have been recorded almost fortuitously in the course of more general investigations of urban areas and Roman estates, at Chartham in Kent for example (Kent HER TR 15 SW 5).

Doubtless there were numerous other Roman quarries in the oolitic stone belt, for example at sites such as Clipsham in Rutland, where all trace appears to have been lost, mainly due to subsequent quarrying. Thus extensive authentic Roman quarrying remains are usually difficult to detect, and documentary and monumental references to quarries very rare indeed. However, Handbridge in Chester and most of the far northern sites, closed completely at the end of the Roman era and were therefore left more or less unmolested by later extraction.

As an example of the focus of archaeological research as a whole, the quarries at Ham Hill, Somerset, are located within England's largest Iron Age hillfort, which has undergone several archaeological investigations since 1823 to the present. However, none appear to have reported on quarrying *per se*, despite its acknowledged Roman associations and regular activity thereafter to the present. Although a detailed 1:1000 scale survey of the site by the RCHME was completed in the mid 1990s, including detailed plans of the quarries, no attempt to analyse the quarry remains was ever commissioned (Dunn 1997).

To redress this situation, over the last decade or so, the University of Reading has begun a systematic scoping of Roman quarries, particularly in southern England, with the emphasis on combining archaeological and geological skills. This has been implemented through the medium of a sequence of PhD studies, including Hayward (2006) on Lincolnshire and Northamptonshire; Bishop (2000) on Quarr Stone; Saunders (1998) on Old Red Sandstone. Following the above, Hayward is coordinating a reference collection of identified stones at the Museum of London.

On an regional or more restricted basis, in addition to the studies just mentioned, Williams (1971a, 1971b) has written on Roman building materials in southeast and southwest England respectively, and Pritchard (1986) has assessed the usage of ornamental stone in Roman Britain, including that from British sources (e.g. White Lias, Purbeck Marble, Alwalton Marble and Chalk). Peacock and Williams (1999) have also produced an interim report broadly on the same subject.

Of particular note is the considerable research interest directed to Roman usage of Purbeck Marble; Pearson (2006), cites no fewer than fifteen Roman studies in which Purbeck Marble was recorded, three

of which were solely on the stone. There is a strong southern bias of research (with the clear exception of Hadrian's Wall zone), which can largely be explained by the preponderance of established Roman development in southern England. However, the lack of archaeological recording of quarries and stone elsewhere may also be a function of the dominance of sandstones in those areas and the perceived difficulty of identifying and, in particular, differentiating between various sandstone sources.

Many local, city or county guides to building stone refer to the Roman use of stones from their respective areas or from further afield, e.g. by Purcell (1966) regarding Cambridge, Arkell (1947) on Oxfordshire and Stoker (2007) concerning Kentish ragstone.

Limekilns, Roman to medieval

Although lime was burned in Europe prior to the Roman invasion, in England evidence is extremely limited, despite lime being an important and much-used commodity in that period (Chitty 2001). Eve & Stead (1998) note that the first lime kilns were operational in Kent, very soon after 44AD.

Roman and Romano-British limekilns, are widely distributed throughout England from Northumberland to Norfolk and across to Somerset, but the majority are located in the South. In terms of research coverage, there appears to be a particular concentration in Bedfordshire, Northamptonshire and Cambridgeshire. Most are isolated but two clusters are known, at Hardwick Park (Northants) and Richborough (Kent). Almost all were supplied by limestone, including chalk, from nearby outcrops. By 1989, archaeological excavations had taken place at 14 sites with 17 kilns (i.e. all known limekilns) in England (Rhatz & Greenfield 1977; Dix 1979). Most work is in respect of single projects; examples include Cardington Mill in Bedfordshire (White 1977), Piercebridge in North Yorkshire (Richardson 1962), Weekley in Northamptonshire (Jackson et al. 1973). However, little has been recorded concerning the related quarries.

Compared with fieldwork on Roman sites, relatively few references to investigatory work on kilns of the Anglo Saxon period have been found, and some writers imply that there were very few active at this time, but include Great Paxton in Cambridgeshire (Lethbridge & Tebbutt, 1935). Other suggested examples near Bath, include Monkton Farleigh and Landsdown Battlefield. Evidence of mortar in buildings of this date would imply that the lime required would mostly have been produced in sod kilns or by similar transient methods.

Early medieval

In archaeological research, stone usage and extraction in the early medieval period has not been treated as

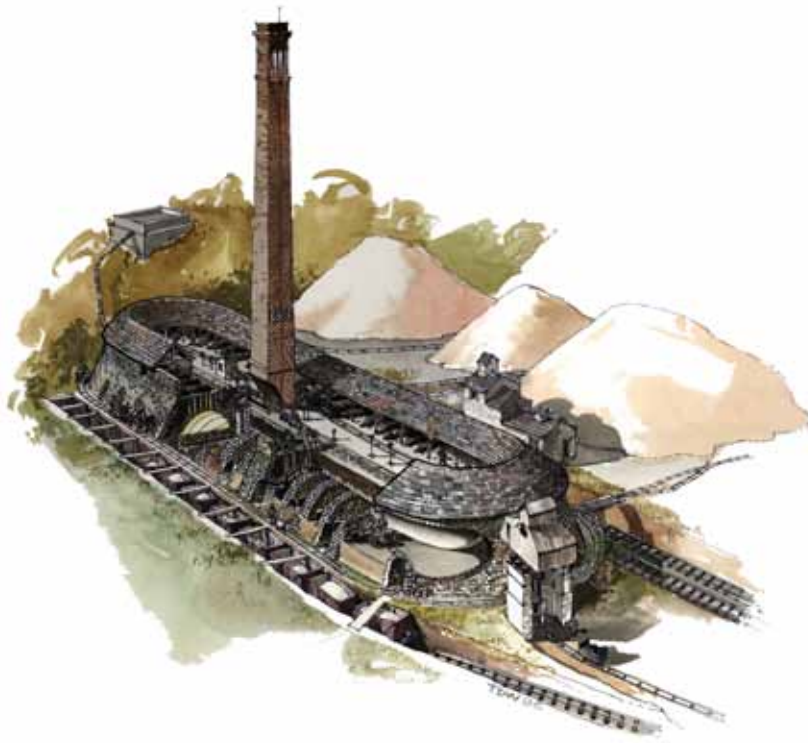


Figure 3.33 Coverage at 'regional' level is generally poor. Johnson's works on the Yorkshire Dales and Stanier on the South West are exemplary exceptions. Reconstruction of Craven Hoffmann kiln, Ribblesdale. Anne Leaver ©Yorkshire Dales NPA

rigorously or comprehensively as for Roman times. Cranstone (1999) refers to only three early medieval quarries (Cold Ashton, Gloucestershire; Mockwood, Devon; and the well known Chilmark Quarries in Wiltshire). No mention is made of Cadman's (1990) detailed report on Saxon through to 12th-century quarries at Raunds, Northamptonshire. Stanley (1990) sought to match the materials used in Saxon Derbyshire churches with stone sources. There appears to have been no follow-up in respect of quarries, to Jope's (1964) comprehensive studies of stone types used in numerous Saxon churches.

Recycling of Roman materials becomes most obvious in the case of readily identifiable Roman bricks, but is less evident in respect of stonework. The robbing of Roman construction materials, has been relatively well covered, perhaps the best example being at Brixworth church, Northamptonshire (Sutherland 1990, 102-113; Sutherland 2003; Stocker & Everson 1990, 83-101). In this instance a multiplicity of Roman sources were identified in an Anglo-Saxon building. The latter authors also track the recycling of stone in Lincolnshire, mainly originating from former Anglo-Saxon buildings.

Medieval

Despite the considerable study of documentary evidence of medieval quarries and of archaeological research on buildings, or remains of buildings, archaeological

investigation of medieval and early modern period quarries themselves, has been very limited indeed. In many cases, buildings and quarries are in close proximity, or are sufficiently described, when applied to geological mapping, for extractive sites to be reasonably precisely located. Although no systematic analysis has been applied, it would appear that the main deterrents to detailed fieldwork in such sites include most of the factors noted in section 3.9.2 and in particular:

- the considerable lateral extent of some sites
- the volume of quarry waste accumulated
- 'assessed' or anticipated paucity of finds or distinctive features
- subsequent surface development
- designation for biological protection
- a reluctance to disturb parkland, wooded or historic landscapes
- subsequent reworking.

Cranstone's list of medieval quarries contains 87 sites in which limestone/chalk workings predominate, followed by slate. The very few sandstone operations are almost entirely confined to millstone production. Granite/igneous quarries do not feature.

It is in the period from c.900 to c.1400 that most of the 'classic' building stones – notably, of the Jurassic stone belt (Doulting, Box, Dundry, the North



Figure 3.34 Lime burning is one sub-sector which has attracted much research, but links with source quarries are frequently lacking. This study of Peak Forest does plot geographical inter-relationships but little evidence was available in the field to add to the picture. © John Barnatt

Cotswolds, Taynton, Barnack, Weldon, Ancaster) and Cretaceous Beer Stone – rose to the fore. Almost all are evident through field and documentary evidence, which supports medieval operations at identifiable sites, though few have been excavated or archaeologically recorded.

Moorhouse (1990, 2007) reports on quarrying, mainly of sandstone in West Yorkshire. Norfolk and Norwich building stone sources are described by Harris (1990) and Ayers (1990) respectively.

Origins of supply to abbeys, cathedrals and other churches, have been a particular focus for research, not only from an academic standpoint, but also in the interests of sourcing and matching for conservation purposes. Some of this work has been reported formally, such as those at Canterbury, Rochester, Winchester and Salisbury (Tatton-Brown 1990; 2002), Rievaulx and Malton in North Yorkshire (Senior 1990, 1999), North Norfolk (Allen 2004) and Lincoln (Jefferson 1993), but most information rests in unpublished fabric reports to owners or grant-aiding bodies. The collation of such information is worth serious consideration.

Portland Stone did not come fully into its own as Britain's most prestigious stone until the early 17th century but it was used in Exeter in 1303 and in London

and Westminster in 1349 (Salzman 1957, 119-39; Morris 1998). However, even for this nationally prominent producing area, although well documented and given a reasonable level of investigation, there appears to be little evidence on the ground of quarry activity prior to c.1750 (Stanier & Cox 1995; 2007).

From the end of 12th century, Purbeck 'Marble' came widely into fashion, particularly for slender polished columns, and it remained in demand for two centuries. Some of its earliest (pre 1200) uses were in Durham and Dublin (Leach 1978). Most of the shaping was carried out at, or near, source (Salzman 1970; Benfield 1940; Saville 1973). Many larger English churches built between 1170 and 1350, incorporated polished dressings of Purbeck 'Marble' (Knoope & Jones 1967, 24).

Another exception to the information deficit, is the investigation of underground workings of this period, particularly in the South and Southeast. However, drawing distinctions between excavations of different periods can be particularly challenging, Beer 'caves' in Devon being a good example (see Section 14.0).

To inform a strategic approach, the period deserves a more thorough literature review than can be undertaken here. The completion of the 'Atlas' series as

part of English Heritage's Strategic Stone Study⁵ should assist this process for all periods but a more focussed historical approach is probably required.

Quarrying post-1540

Cranstone et al. (1999) reported that the largest group of sites in chronological terms belonged to the post-medieval period and, within this, there was a marked bias from the 18th century onwards. They only recorded four 16th-century sites, and these are: Coniston slate quarries, Cumbria; millstone quarries at Lyham Hill, Northumberland; Llanymynech and Pant Quarries, Shropshire; Godalming Crownpits, Surrey. Of subsequent activity, Cranstone's report indicates that 'millstone' (presumably embracing other abrasive stones), lime burning and dimension stone accounted for the bulk of surface-based extraction, at least until 1900, with lime production, dimension stone, slate and flint being won from underground. For the period after 1900, Cranstone cited 29 sites with dimension stone, mostly in the Southwest and to a lesser extent Yorkshire and the Southeast. Aggregates predominate in the Southwest, Northeast and, less so, in the Midlands. While noting that many modern sites do not lend themselves to protection, Cranstone advocates that 'it is important that a representative range (several), including working examples, are preserved by record'. He goes on to suggest that Callow Hill (Somerset) might be a suitable candidate.

After c.1650-1700, where resources were available, almost every village had one or more quarries; sometimes these are documented in parish records. However, only exceptionally have they been investigated in the field and reported, as in the research by Thomas (J Thomas 1998a, 1998b & 2008) on the Dorset vernacular stone industry, and the work by Sutherland (2003) in Northamptonshire.

Regional coverage

Regional coverage has been down to the assiduous efforts of individuals, rather than the result of strategic or institutional approaches. The following can be quoted as exemplary: Stanier in the Southwest, especially the granite areas, but also Purbeck and Portland. Work by J Thomas over many years on Dorset, and Sutherland's studies of Northamptonshire, are summarised in their respective 1998 and 2003 publications; in the context of building stones, both stand out as detailed, almost forensic, analytical and often multidisciplinary templates to follow. Johnson's (2002 & 2010a) research in the Yorkshire Dales balances the relationships between quarries as a whole, and downstream processing, notably lime burning, especially in the later 19th and 20th centuries. Stanier and Cox (2007) have reviewed the remaining evidence of former quarrying on

Portland, which dates from post 1750. Cooper's work on the Trent (2008) appears to be the only research covering the development of sand and gravel working, although history outweighs archaeology in this case. Anon (2004) and Eve and Stead (1998) considered the remains of the chalk and cement industry in Kent and Essex.

3.9.4 Gaps - regional resources

However, there are large gaps in broad scale archaeological reviews, notably in the three premier concentrations of modern-day quarrying, in the Peak District, Charnwood in Leicestershire and the Mendip Hills, although accounts await completion and publication. The exploitation of the chalk over south-eastern England, most of the Pennine sandstones and many parts of the Jurassic belt, is still very poorly covered, although much research has been conducted. Sand and gravel extraction outside the Trent Valley are the most neglected sector of all.

Local level

Below regional level, for the post-medieval period, there are some excellent localised sandstones analyses, such as Rossendale, Lancashire (Gregory & Lloyd 2003); Pateley Bridge/Nidderdale in the Yorkshire Dales (Blacker 1995; 1996); quarries in the Hambleton Hills, North Yorkshire (Cooper 1977). Further fieldwork on sandstone units is understood to be in hand in the Haworth area of Yorkshire.

Andrews and Andrews (1983) produced a reconnaissance study of mid-Staffordshire quarries and Christiansen (2010) compiled a report on the field and historical evidence of mainly mid 20th-century quarry processing plants in Worcestershire. In addition to the work of Stanier (1985a-c; 1986a & b; 1987; 1999) at many granite sites in the Southwest, Sturgess (2000) reported



Figure 3.35 Haytor Quarry, Dartmoor displayed a unique and innovative means of transport in 1820 utilising granite 'rails'. © Phil Newman

on California Quay, Cornwall. Detailed earthwork survey was carried out at all five of the Haytor Granite quarries, revealing that much of significance can be determined using this technique (Newman 1999a; 2003; 2011).

Estate accounts may provide documentary evidence, but as the workforce and haulage was mainly carried out in house, it is often only the imported materials, or perhaps those for an estate school or church, which may be specifically recorded (Durant & Riden 1980 and 1984). Apart from some landscape archaeological projects such as that at Chatsworth, Derbyshire (Barnatt & Williamson 2005), relatively little fieldwork has been undertaken on the role of estate quarries, although their location is often reasonably well known, or widely assumed, particularly from archived estate plans.

Niche producers

Certain relatively small sectors have attracted a disproportionate amount of investigation, which is not commensurate with their scale in the wider quarrying context. All have particular characteristics, which attract researchers. The most popular, abrasives, has been stimulated both by the presence of obvious field evidence and the direct links with the preponderance of finds in mainstream archaeology. Slate workings are often relatively large, remote or isolated and were often corporately run, requiring substantial capital. The remains of lime burning are frequently quite evident (although not always the source quarries), and working of decorative stones was a relatively exclusive practice (often involving mining), usually producing a readily identifiable product from a specific geological horizon.

Abrasives

Most abrasive stones (except pulpstones and to a degree, grindstones) have received considerable research attention (Hockensmith & Ward 2007), which typically focuses upon a specific quarry, or area source, and plots the distribution of usage.

Second only to querns (see above) are the investigations into millstones. Tucker (1977 and 1985) traces in detail developments in millstone production. However, the sequence of fluctuating fortunes and products has only been informally and very briefly summarised (Thomas 1997). A more comprehensive approach will be fundamental to understanding some of the finds and the varying uses of terminology.

For whetstones/honestones, Ellis (1969) has discussed Anglo-Saxon and English medieval material, Moore (1978 & 1983) and Crosby and Mitchell (1987) have presented metamorphic examples of the c.9th-15th centuries.

A very small specialist use within this category is

as touchstones, used to test whether a metal object is made of gold and the proportion of gold contained in alloys. Moore and Oddy (1985) reviewed these from the 6th century BC onwards and indicated that tuffs, cherts and siltstones were the most frequently utilised.

Lime burning

Lime burning, in contrast to other topics of this period, has been widely investigated. However, as with earlier periods, the associated quarries have received scant attention and in many cases, quarries are detached from the burning operations. Studies cover the whole spectrum from county-wide reviews to detailed measured surveys.

For the MPP Step 3 report, Trueman (1997) recorded limekiln investigations across England. Examples of broadbrush reviews include Herefordshire (Goodbury 1994), Dorset (Stanier 1993), Cornwall (Isham 2005), Forest of Dean (Wilkinson 1992), Teesdale (Wilcock 1998), Central Pennines (Johnson 2010b), Yorkshire Dales (Johnson 2010a; Whight 2006), Surrey (Robinson & Cook 1962), North and West Dartmoor (Born 1991), North Devon (Collins 1991), Exmoor (Holley 1997), Avon (Taylor 1984), Kent (Eve & Stead 1998), Sussex (Martin 1997) and Sedbergh/Garsdale/ Dent (Cleasby 1995). Leach (1995) mapped pye kilns in the Peak District.

Examples of individual site surveys include: Foredale, (Johnson 2006) and Langcliffe (Dennison 2001), both in Yorkshire; Ticknall (Palmer & Neaverson 1987a), Turnditch (Woore 2002) and Peak Forest (Barnatt & Dickson 2004), all three in Derbys; Calstock, Cornwall (IA Thomas 1998); Temple Meads, Bristol (Good 1987); East Castle, Co. Durham (Manchester 2000); Walford, Shropshire; Ross-on-Wye, Herefordshire (Morgan 1993); Barrow on Soar, Leicestershire (McAree 2007); Old Cleeve, Somerset (Daniel & Murlees 1993); Newbridge, North Yorkshire (Borman 2009); Meldon, Devon (Fletcher et al. 1997).

Although a handful of vertical lime, and even fewer cement, kilns from the later modern period still exist, little attention appears to have been paid to them and in particular to metal kilns. As far as can be ascertained, no old rotary kilns have been preserved and many have been removed in the last 25 years, but apart from possible long disused jetties, precious little evidence remains of the 20th-century cement industry.

Decorative stone

Dennison and Richardson (2007) have investigated the Dent Marble works, Cumbria, and in the Peak District, Thomas (2005) covered the residue of the Hopton Wood stone industry. Relating to slightly earlier periods, Barnatt (2005) explored the Ricklow 'marble' workings, while Ford (appendix in Tomlinson 1996)

mapped the Ashford Black Marble Mines. In parallel, a large number of accounts cover the historical use (rather than fieldwork on extraction) of Purbeck in Dorset, Frosterley and Eggleston in Co. Durham, and other 'marbles'. Walkden's (2015a & b) exhaustive, mainly historical and geological, account of the South Devon 'marble' industry, also describes sites in the field.

Slate

Historical accounts cover almost all the main metamorphic slate producing areas in England and, in addition to providing a useful framework, often include plans and archaeological details. The main examples include: Born (1988) on slate quarrying in South Devon; Lorigan (2007) on Delabole, and Sharpe (1990) on Tintagel, both in Cornwall; in Cumbria, Tyler (1994) on Honister and Cameron (2005) on Coniston, Geddes (1975) on Burlington; Brittan and Ramsey (2007) on Leicestershire (principally Swithland).

Fissile sandstone and limestone, extracted for roofing have been extensively investigated both historically and geologically and are reviewed by Hughes (1996a & b; 2003; English Stone Forum website⁴; these contain extensive bibliographies) though archaeological investigations are relatively rare, but include Aston's (1974) study of Stonesfield, Oxfordshire.

Mines

Some of the preservation hazards faced by surface operations, such as the threats of removal or vandalism, are far less prevalent in underground mines (although some issues such as flooding and safety may often be greater). The sequence of working may define relative, rather than actual, dates of extraction. Tool marks are frequently evident and the tools themselves may have been discarded (McCann 2002).

There is a further notable difference between surface and underground reporting. Subsurface working represents an extremely small proportion (generally much less than 1%) of total bulk minerals extractive effort, yet, in relative terms, it is extremely well covered archaeologically, driven in part by a general interest in 'getting underground', and in the last few decades, by the need to assess and treat surface stability hazards. Knowledge gained from underground research, therefore, tends to be disproportionate to that gained from former surface working.

The most extensive stone mines are around Bath, and the recent work on the Combe Down mines, in advance of filling to stabilise surface hazards, is a model for others (Willies et al. 2011). Other areas of limestone mines explored in detail include the Whittington area in Gloucester by Price (2007), Lilleshall and Church Aston in Shropshire by Adams (2007), Dudley mines, West Midlands by Powell (1999), and in Derbyshire, the



Figure 3.36 Although several thousand plants making coated roadstone, concrete products or ready mixed concrete (RMC) have operated in England, it is very doubtful if a single example has been recorded, let alone preserved. The first RMC plant started up at Bedfont, Middlesex in 1930, is seen here c.1950. © CEMEX

Bakewell chert (Critchley & Wilson 1975) and Ashford black marble mines (Tomlinson 1996).

Twenty to 30 extensive underground workings are recorded in the Upper Greensand between Dorking and Godstone, Surrey (Sowan 1976) and the ancient mining operations for building stones are particularly prolific in Chaldon, Gatton, Merstham and Reigate (Kent). The Chaldon – Merstham complex alone has almost 17km of accessible and surveyed tunnels (Bailey unpub; Burgess 1983, 1987, 1994a, 1994b; Sowan 1974, 1984, 1987, 1991, 2000).

Processing

With the notable exception of lime-burning, and, in a few instances decorative and even more rarely, building stone, almost all the archaeological investigatory work cited above has concentrated upon recording extractive (and waste disposal) rather than processing activities. Almost no primary processing sites for the mainstream sector of the industry, namely aggregates, have been recorded. The work by Christiansen (2010) is probably the only example.

Most forms of secondary processing such as

concrete batching, are even more poorly represented. For example, from several thousands of concrete batching, concrete product or coated roadstone plants operational since the 1930's, it is doubtful if a single one has been preserved or even recorded (although some non-operational older plants may remain temporarily mothballed). The same probably applies to other types of secondary plants such as those manufacturing mastic asphalt and mortar.

3.10 Conclusion

The geographic and chronological extent, population and sheer range of bulk mineral sites are unmatched within the context of extractive industries. These industries have been so badly served in respect of archaeological research, that they demand special treatment. The Research Agenda for bulk minerals must therefore address key characteristics of the sector. Many of these features are often not necessarily unique, but may be present in accentuated form. Overriding factors include:

- ubiquitous presence – limestone (including chalk), sand and gravel have been extracted in every historic county of England and sandstone in almost (if not) all such areas
- number of sites – greatly exceeds any other category of extractive activity
- range of products and markets and volume of output – more extensive than any other category of extractive activity and to a lesser degree, processing techniques display a considerable variety
- chronological and geological range is greater than for all other mineral production
- highly active industry today – more bulk minerals produced in the last 50 years than in all previous history, probably exceeding the collective historic output by tonnage of all extractive sectors – as such, much of the previous field evidence has been overwhelmed and frequently removed by subsequent extraction or at the insistence of planners
- imbalances in research coverage – attention directed to certain aspects ('low hanging fruit') e.g. excellent work accomplished on abrasives, flint, prehistoric period, slate, Purbeck 'Marble', underground operations, lime burning; compared with highly neglected but very significant sectors such as sandstone, aggregates and sand/gravel
- stone's role in archaeological endeavour and building conservation – probably larger than any other material, but knowledge of its attributes

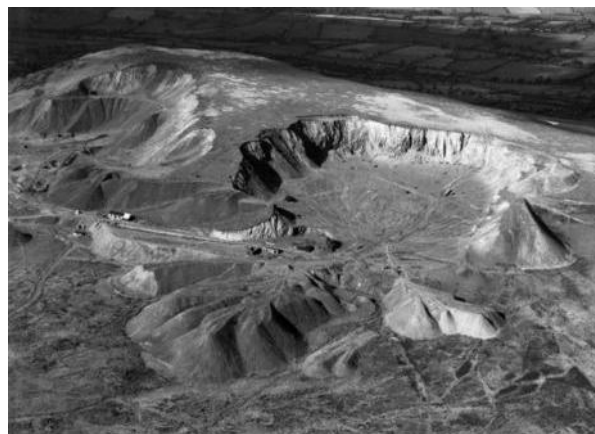


Figure 3.37 Titterstone Cleve Hill Quarries in 1948 showing typical 'finger dumps'. Older evidence has usually been quarried away or removed by landscaping, but these still remain. © Aerofilms / HE copyright EAW020123

(provenance, age of extraction, composition) is often at best generic, regularly misinformed and generally far less subject to scientific scrutiny, than say timber or metals.

These factors are not new and have been raised previously, sometimes emphatically, notably by Peacock (1998), Cranstone (1999) (both commissioned by EH), Parsons (1990a) and in EH's own review, *Mineral Extraction and the Historic Environment* (2008).

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4 Coal

Mike Gill

Additional material contributed by John Barnatt, Graham Brooks, Ivor Brown, Nigel Chapman, Peter Cloughton, David Cranstone, Paul Deakin, James Fussell, Shane Gould, Fred Hartley, Phil Newman, David Poyner and Rob Vernon

4.1 Locality

Coal occurs over large areas of midland and northern England, with smaller coalfields in Somerset and Gloucestershire, Devon and Kent. However, much of it remains unworked because it exists at too great a depth. Nationally, the industry's archaeology is not evenly spread, with large tracts of surface evidence having been removed by opencast mining, urbanisation and landscaping. The Bristol, Nailsea, North Somerset, and Forest of Dean coalfields have a relatively high proportion of well-preserved sites, but important remains can be found in almost all coalfields. There are significant remains of coal mining in the Pennines, dating mostly from the 18th and 19th centuries, but with some older and a few more recent. Archaeological evidence sometimes survives in places where coal has been sought, but never found or worked. There are also coal fields in South Wales and Scotland, which, although outside the brief of this assessment, need to be considered in any general statement about the archaeology of British coal. Records for coal mines, collieries and associated infrastructure are contained, to a greater or lesser extent, in the HERs for Cheshire, Cumbria, Derbyshire, County Durham, Gloucestershire, Kent, Humber, Lancashire, Leicestershire, Manchester, Northumberland, Nottinghamshire, Shropshire, Somerset, Staffordshire, Tyne and Wear, Warwickshire, Worcestershire, North Yorkshire, South Yorkshire, West Yorkshire, Yorkshire Dales National Park and North York Moors National Park.

4.2 Consumption

Coal is a dirty fuel and, depending on its rank (carbon content), some is more so than others. This dirt, in the form of ash and volatile matter, especially sulphur, is a particular problem for many applications. Where such coal was directly in contact with the raw materials being treated it contaminated the product. Nevertheless, coal was used as a domestic fuel from Roman times when it was also used for lime burning and smelting.

Consumption of coal in Roman times is hinted at

in various archaeological contexts (Dearne & Branigan 1996) though its use was probably on a small scale. Even by the 13th century, when early documentary evidence of coal usage is available, it was not favoured as a domestic fuel and wood and peat were preferred. In the early post-medieval period, rapid population growth, especially in towns, outstripped the traditional domestic fuel supplies and led to the coal industry becoming well established by the 17th century. Some land owners may have responded by reserving their wood for industrial rather than domestic purposes, but recent work in the Wyre Forest suggests a local preference for burning wood well into the late 17th century (Poyner & Evans 2000). The authors of that study admit this activity was probably atypical because people there were able to obtain firewood easily. The change to coal was certainly not universal, and many other rural areas continued using wood or peat for domestic fuel, where for many the only outlay was in the effort of gathering it.

Earlier writers, for example Nef, might lead one to conclude that demand for a larger output of coal was met by innovative changes in the industry's structure and management plus larger, much more highly capitalised mines (Nef 1966). On the contrary, however, as Burt demonstrated for metal mines and as Hatcher also points out, with few exceptions, these increases were achieved by sinking more small mines and using traditional techniques (Burt 1989; Hatcher 1993, 10). The domestic demand was for lump, preferably low-sulphur, coal whereas small coal and 'slack' was sold for lime burning or salt making, aiding the viability of many rural and coastal collieries.

Because it was difficult to transport bulk loads, until the 18th century, most English collieries were small affairs, serving local markets. The coal trade grew disproportionately in the Tyneside and Wearside area, where larger collieries appeared, in response to the coastal trade with London. This lead was sustained by the introduction of wagonways in the 17th century, which allowed mining to spread both north and south of the Tyne. Similar developments on a smaller scale occurred in West Cumberland, supplying the Irish



Figure 4.1 The English coalfields. © NMRS

market, and collieries around Coalbrookdale, in the Severn Gorge, where the river was used to ship coal to Worcester and Shrewsbury. This trade was enhanced by using local coal and limestone to produce lime. The same mines also produced ironstone with their coal and an iron making industry was well established before 1709 when Abraham Darby began the commercial smelting of iron with coke.

Darby's success coincided with Newcomen's introduction of the atmospheric engine, near Dudley, in 1712. For precision foundry uses, pig iron made with coke was better than that made with charcoal, which helped advance the atmospheric engine's

development. Together they raised demand for coal and, in turn, facilitated deeper and more centralised collieries. Nevertheless, these two developments, while paradigmatic in their approach, only steadily increased the market for coal, but they allowed major advances in engineering, manufacturing techniques and skills to evolve.

In 1848, the Scottish chemist James Young (1811-1883) began trying to extract liquid fuels from cannel coal at Alfreton in Derbyshire. However, this supply soon ran out, and Young found an alternative supply at Bathgate in Scotland. Also, in the 1840s, the first Benzene was commercially produced from coal tar

sources, and these two events marked the start of a massive demand for coal from the chemical industries,

A major advance in markets came with the canal age, when rural and urban areas became linked and bulk transport between inland areas independent of navigable rivers became possible. By the 19th century, therefore, the economy had reached a critical mass, with an insatiable demand for raw materials, especially fuel – now almost exclusively coal and coke.

Steam power was paramount in the 19th century and the only significant fuel available to power it was coal. It drove mills, mines, railways, steamships, foundries, breweries, potteries and practically all other means of production. In addition, the metallurgical and coking grades of coal were in great demand for iron smelting and gas making. Some collieries became larger and deeper and often worked a number of seams from a central site. By far the majority, however, remained quite small.

Coal prices and production regularly oscillated in the 19th century following a roughly five year cycle, but what historians call 'the coal famine' occurred between 1871 and 1873. This caused the price of coal to rise from around 9s 6d per ton to 21 shillings over two years before falling back to 10s 10d in 1876 (Meade 1882, 310). The cause appears to have been a relatively small under-supply in an otherwise buoyant market, and many new collieries were started as a response to it. A further knock-on effect was that alternative fuel supplies were sought, and much experimentation and investment in the commercial development of peat occurred in areas of England and Ireland where the fuel was plentiful. However, these were mostly unsuccessful.

Employment statistics for the coal industry are not available until the mid 1890s, but it is possible to gauge the number of English collieries from 1854 onwards. The *List of Mines* shows a rise from 1,845 mines in the year 1855 to a maximum of 2,596 in 1880. From 1885 to 1895 it averaged 2,245 before beginning a steady, but relentless decline (Gill 2007). The decline from 1895 onwards partly reflects the closure of older, smaller and shallower mines and their replacement with fewer, larger, often deeper, and more efficient mines. However, over the long term it reflects over-capacity in the face of changing markets, with the rate of increase in coal production starting to slow after 1870, and production declining after 1913 (Mitchell 1984).

Coal mines were highly labour intensive, and, from the 1860s onwards, some owners responded by introducing mechanical coal cutters to cut production costs (Gill 2009, 116-23). However, by far the majority did not do so until the early 20th century, when electricity, gas and oil were changing the shape of the

market for fuel. For example, the launching of the Royal Navy's first oil fuelled battleships (Queen Elizabeth class) in 1913 began a rapid changeover to oil. In addition, competition from coal mined overseas hit Britain's export market badly. From the early 1920s, therefore, it was government policy to encourage the closure or merger of collieries into larger, more productive units.¹ Production quotas were set in order to avoid even higher unemployment, with many mines working only part-time.² As part of this process of rationalisation, the Conservative Government nationalised coal reserves in 1938, with effect from July 1942.³ The mines themselves were nationalised from January 1st 1947 under the National Coal Board (NCB).⁴

Between 1926 and 1937 the national electricity grid was built, in order to link power generators and encourage the use of electrical power by industry. The nationalisation of the power generators in April 1948 was followed by moves to build large, new, often coal-fired, power stations on the coalfields.

From its onset the NCB followed the policy of merging collieries, closing unproductive mines and absorbing their reserves into the takes of neighbouring collieries. Some mines were closed to provide land for opencast mining. Throughout the 1950s and 1960s, marginal, high-cost coalfields (Somerset, Shropshire, Cumberland and West Durham) were run down and their workforces were encouraged to move to 'long life' collieries in Yorkshire, Derbyshire, Nottinghamshire and the Midlands. This diaspora will be reflected in settlement patterns and regional demography as, particularly in Durham, whole areas of housing stock were classified for demolition, sometimes to make way for opencasts.

The markets shifted again in the 1950s and 1960s as industry turned to oil, electricity and gas for its power. This move was accelerated by Clean Air legislation and the use of diesel and electric-powered railway locomotives. As well as continuing to rationalise its mines, the NCB also sought to mechanise them wherever possible, and concentrated on supplying the electricity generators.

Nevertheless, nuclear, oil and gas-powered generating stations made major inroads into coal's principal remaining market and the industry had shrunk to fifteen large mines when the NCB mines were privatised in 1994 and by 2011 that number was reduced to five: Kellingley, Hatfield, Maltby, Thoresby and Daw Mill; of these five, all had closed by December 2015.

Their principal market was the electricity generators, but Maltby also served the Monckton coke works. There are also smaller mines at Eckington, Clayton West (now closed) and in the Forest of Dean.

4.3 Geology

Most English coal deposits, traditionally referred to as the Coal Measures, were laid down during the Westphalian regional stage of the Carboniferous period when, between 313.5 and 306.5 Mya (million years ago), extensive freshwater swamps sometimes flourished on deltas or behind coastal barriers at tropical latitudes.⁵ There are also the Culm measures of North Devon which are problematic in age, but are probably Westphalian. They are anthracitic in nature and were probably formed on the margin of the main delta.

The sediments were predominantly sands, silts and mudstones, but where they broke waters the surface peat accumulated in swamps, which rotted under anoxic conditions and eventually formed coal. It is estimated that it took the peat approximately 10,000 years to reach a thickness of 10 metres; enough to make around one metre of coal. These deltaic areas subsided slowly (from 1 to 5 mm per year) as, under their increasing weight, the sediments became compressed.

The rate of subsidence was often equal to the rate that sediments accumulated, but occasionally the process was interrupted. Commonly, the process of peat formation would be ended by the deposition of mud. However, tectonic activity could also cause the landmass, which provided the source material for the deltas, to be uplifted at a faster rate. Such an event would increase the rate of erosion on the land and permit the deposition of sand or grit in the deltaic area. Sediment would cover the peat, and the peat was often eroded by the changing river patterns. More rarely, an increase in the rate that the delta subsided could result in a marine incursion. As a rule, marine bands that result from such incursions, usually form the roofs of coal seams, and are useful for correlation purposes.

Generally, the cycle of deposition followed a set sequence. The peat would be covered by mud grading upwards into sand. Eventually vegetation would become established in the semi-submerged sand, which would then be invaded by roots, to form a seatearth, or fireclay, on which the peat would accumulate. This characteristic sequence of deposition is known as a cyclothem. This cycle of swamp–subsidence–flooding–sediment infill–swamp was repeated many times over, which is why coalfields usually have a sequence of coal seams, and may reach a total thickness of hundreds of metres, even though all the sediments were deposited in shallow water.

Faulting also affected deposition. The slow movement of basement faulting beneath the deltas could cause variations in sedimentation. If these ancient faults remained active, it would cause differential rates of subsidence on either side of them. While sediments

might continue to accumulate on one side, on the other they might become flooded and covered with sediment until a new swamp formed. Thus, what had been a thick seam might appear to split into two or more thinner ones. This process could also happen where surfaces subsided differentially for other reasons, but it always had a profound effect on the layout of mines and their workings (Williamson 1999, 5-27).

The coalfields in central and northern England were uplifted when the Pennines formed and, except for small outliers left by major faults (e.g. the Ingleton and Sleightholme coalfields), those areas have eroded to reveal the core of older rocks. Subsequent ground movements caused further, localised uplift, tilting, buckling and fracturing of the strata. Again, these effects are major determinators of a mine's layout. In particular, it meant that seams outcropped, allowing early miners to find them and work them from drifts or shallow shafts, before progressing to deeper, concealed coal. Of all Britain's coalfields only Kent's does not outcrop. Its presence was realised by extrapolating French geology westward, and it was then discovered by boreholes.

Older coal seams, in Brigantian (330 to 326.4 Mya) and Namurian (326.4 to 313.5 Mya) strata, were also worked (Gill 2008).⁶ Although generally quite thin, these seams were of considerable local importance for lime burning and domestic fuel. Sometimes their coal was cokeable, which added value. The Namurian seams in particular were formed on an active paleo-surface of river channels, sand banks, flood plains and lagoons, in which coal swamps formed on sand or mud substrates. It is possible, therefore, for seams to be broadly coeval, but not necessarily conjoined. Periodic incursions of sediment-rich water into the lagoons from river channels, or sea, caused the high ash content common to such seams.

Younger coals have also been worked in Bajocian age rocks of the Mid Jurassic epoch, dating from 171.6 to 167.7 Mya, on the North Yorkshire Moors (Gill 2010a). Unlike the Carboniferous-age coals, these Permian–Jurassic coalfields originated in temperate latitudes. Small deposits of lignite, an even younger, soft brown coal, found in chalk (145 and 65 Mya), were worked at Cobham in Kent. Lignite was also worked around Bovey Tracey in Devon (Pengelly & Heer 1863). It formed in the Lower Miocene epoch, of the Neogene Period, and dates from between 23 and 15.9 mya.

As well as coal, the Carboniferous Coal Measures supported a range of extractive industries. These included clay for brick making, sandstones, which were quarried for building stone, and the seatearths for fireclay and ganister. Clay ironstones were also locally important. They were formed in the reducing conditions within the freshwater swamps, where iron

went readily into solution. When oxidised the iron would precipitate and combine with carbonates to form sideritic mudstone. Some iron-rich horizons formed thick ironstones that were economically important, like those in the West Midlands or the Tankersley Ironstone of Yorkshire, for example (Raistrick 1939; Hemmingway 1974). Ironstone could occur in beds, as nodules or, less often, impregnated sandstone. Iron also combined with sulphur, which was freely available in swamps, to form iron pyrites (FeS_2), which occurs as nodules in some seams and was used for making copperas ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$). Sulphur was also a major pollutant in some coals.

4.4 Historical research

Much has been written about the UK coal industry, but we know relatively little about it in detail. The major recent work, a British Coal-sponsored five-volume study of *The History of the British Coal Industry* deals with the industry nationally (Flinn 1985; Hatcher 1993; Ashworth 1986; Church 1986; Supple 1987). These volumes give a useful outline of the industry's progress within the national context of markets, legislation, attempts to increase productivity, etc. The pre-1982 literature is summarised in Benson (1981) who, along with others, has recently published a six-volume compilation of sources, *Coal in Victorian Britain* (Benson et al. 2011-12). There is a very considerable literature on the social history of coal mining, both on the miners themselves and their communities, and also the trade unions and industrial relations (Benson 1989). Page Arnot's multi-volume history of mining trade unionism until the mid-20th century remains a key text (Page Arnot 1949, 1953, 1961, 1979), while more recent writers have focussed on the disputes of the 1970s and 1980s.

The *Gazetteer of UK Collieries*, designed as a research tool by Mike Gill, is a comprehensive listing of post-1854 collieries and their locations where known (69% of around 12,700) (Gill 2007, 64-75). Older sites are included where details are known, but there are many to be added. A separate database includes details of ownership, management and numbers employed from 1855 onwards (NMRS database). The NMRS website also provides on-line mapping, compiled by Mike Gill, which shows the locations of over 13,000 collieries in the British Isles using has interactive maps of all UK coalfields showing NCB collieries. The latter are linked to a growing body of thumbnail histories. The Manchester – Wigan area collieries are covered in greater detail.

County and other volumes on 'industrial archaeology', such as the former David & Charles series, e.g. Lancashire (Ashmore 1969), Northwest England

(Ashmore 1982) and the East Midlands (Smith 1965), normally include substantial coverage of any coal mining within their geographical area if coal was produced there. Unlike metal mining, however, there have been comparatively few 'in-depth' studies of specific collieries or coal mining areas (but see below). Railways served a major function in coal mining, however, railway historians tend to enthusiastically follow the track up to the colliery gate, but rarely look over it. There is a wealth of 'Blood on the coal' local studies of explosions, inundations, strikes, lockouts and mining communities, but these rarely give technical details about the mines concerned, or consider their economic history, and can contribute little to the understanding of the archaeology. The last twenty years has seen a growing number of mining historians showing interest in coal mining, and guides have been written to aid those beginning a project (Hill 1991; 2000; 2011; Martell 1999; Henesey 2004). A high proportion of modern books have been based on collections of photographs (e.g. Bower 1993; Ellis 1995; 2002; Franks 2000), and these are, potentially, of great use to archaeologists in identifying component parts of some sites.

Studies of those collieries which worked in non-Westphalian rocks have also appeared recently. These were largely ignored by the Monuments Protection Programme (MPP), which deemed them to be of low national interest/value. Nevertheless, these mines, which generally worked thin seams with high ash contents, were often of local importance over several centuries and their remains may be better preserved than collieries in the main coal-producing areas. Barnatt and Heathcote's studies of workings in the Namurian (Millstone Grit) rocks on the east and west flanks of the Pennine Anticline in Derbyshire appear in various issues of the *PDMHS Journal* and *Newsletter*. In the Yorkshire Dales, the Namurian has also supported extensive collieries (Preston Moor Colliery, in Wensleydale, has around 200 shafts in an area 3km long by 1.5km wide). Where plans have survived, these shafts are shown to have served complex areas of pillar and stall workings. The Viséan in the Yorkshire Dales also produced coal, much of which was used for lime burning. Tyson and Spensley have researched specific collieries, while Kelly and Gill have recently written complementary overviews of the west and east parts of this region respectively (Tyson 2007 and *forthcoming*; Spensley 2014; Gill, 2008; Kelly 2008).

In the North Pennines, there are some Namurian (Millstone Grit) coals, but the most extensive seam was that below the Little Limestone. Normally a bituminous coal, in places around Alston, its rank (carbon content) has been raised to that of a semi-anthracite by heat and pressure during the intrusion of the Whin Sill. Much work remains to be done on this area, but Graham

Brooks is currently researching the western fringe of the North Pennines and the Caldbeck area, on the northern edge of the Lake District (Brooks 2009, 124-36).

Coal also occurs in areas where the strata are more recent than Westphalian. For example, on the North Yorkshire Moors there are extensive areas of coal workings in Jurassic rocks (Gill 2010a, 19-31). The Lignite formation of Bovey Tracy, in Devon, known as 'Bovey Coal' was first described by Milles in 1759 (Milles 1759, 534-53). It received scant attention since Pengelly and Heer's work in 1862, although recently, Edwards has devoted an illustrated chapter summarising the history of extraction at this unusual site (Edwards 2011, 136-52). However, research is lacking at the culm/anthracite workings around Bideford, which are also within Westphalian strata.

4.5 Historical studies of the English coalfields by county

Cheshire

The area exploited for coal in Cheshire is a southern extension of the Lancashire coalfield (see below), but coal working was restricted to the Pennine fringe to the east of the county and Neston, on the Wirral to the west. The Neston collieries have been researched by Annakin-Smith (2006) and a history of the mines around the Poynton area, near Stockport, has been published (Shercliff et al. 1983). Elsewhere in the county, the deposits are too deep to be worked economically, being covered by Permian and Triassic strata.

Cumberland (modern Cumbria)

The coal industry has been included on the pages of the *Transactions of the Cumberland and Westmorland Antiquarian and Archaeological Society* (Old and New Series) from a surprisingly early date including Isaac Fletcher's 'The Archaeology of the West Cumberland Coal Trade' (1877, 66-313), but more recently Oliver Wood's work on West Cumberland Coal 1600-1983 (Wood 1988). Other themes covered are colliery settlements (Harris 1974, 118-46). In the eastern part of the county, there is Webb's useful study of Lord Carlisle's rail network, serving his pits on the Tindale Fell and Midgeholme coalfields (Webb 1978) and in the west, Brayton Domain collieries have been covered by A and B Thomas (1986). A recent study by Cranstone has reported on various historical aspects of coal in the Whitehaven area, and highlighted the potential of a number of untapped documentary sources that could be informative for this area of West Cumberland (Cranstone 2007).

Devonshire

From at least the 17th century, narrow, vertically bedded lenses of anthracite in the Lower Culm Measures were worked at Hartland and from Abbotsham eastwards through Bideford to Hawkridge in the Taw valley. The peak period of production was in the 1840s, at East the Water on the Torridge at Bideford, but small scale working continued into the 1920s. Associated paint pigment working at the Bideford Black Mine did not cease until the 1960s and Claughton recorded inclined shafts and adits in Cleave Wood, extending east for 400 to 800 metres (Claughton 1994, 1-4)(see Section 11).

Lignite was worked intermittently at Bovey Tracey from about 1750 until 1945 (see above).

Derbyshire

In Derbyshire, the main coalfield is a southern extension of that of Yorkshire and so reflects its geological character in many aspects. In turn, it dips eastwards into Nottinghamshire and Northeast Leicestershire. There was a significant ironstone mining industry around Clay Cross.

Members of the Peak District Mines Historical Society (PDMHS) have been active in recording the workings in this county. The work has been published in *Mining History* from 2002 onwards, predominantly by Heathcote (2002). There are also regular reports on small coal workings by Barnatt in the PDMHS *Newsletter* over the same period. The latter also undertook detailed surface archaeology surveys/analyses of Goyts Moss colliery (Barnatt & Leach 1997, 56-80). In addition, there have been studies of mining around Whaley Bridge (Leach 1992) and in the Buxton coalfield (Roberts & Leach 1985). Heanor & District Local History Society (1993) have researched collieries in that area, including Bailey Brook, and Alfreton has been examined in terms of post-war change (Knifton 1985). The *Derbyshire Archaeological Journal* carries papers on Swanwick mine (Johnson 1953, 114-20) and West Hallam (Postles 1979, 221)(see also Leicester below).

Durham

Relatively little recent work has been published, but there is the Durham Mining Museum Website.⁷ This also covers Cumberland, Westmorland, Northumberland and North Yorkshire. It is a very useful site, but has some problems with the reliability of information given. Emery covered the technical development of collieries, coke making and pit villages (Emery 1992). Recent surveys include Temple (1994 and later volumes); Guy and Atkinson (2008, 41-75) include an excellent outline of the coal industry in West Durham (which covers most of the exposed coalfield).

Forest of Dean and Newent

This area is famed for its Free Miners, which appears to make it the only coalfield with any form of organisation, which was broadly analogous to the King's Fields of lead mining history. Coal mining is documented here from the 13th century (Youles et al. 2008, 51). As well as coal mining, this area supported an important iron industry. Occasionally, coal is still raised in this area though in a very small way. Youles has reported on a project to record an area with a high density of pre-17th century coal pits, many less than 20m apart, which appear to have worked three thin seams (see Section 4.8; Youles 2003; 2004). Mining in the Newent coalfield, an outlier of the above, appears to have ended in 1880 (Bick 1979).

Gloucestershire – Bristol and Somerset

The Bristol coalfield runs northeast from the Bedminster area, under what are now the eastern suburbs of Bristol, to Yate, and is associated with the Coalpit Heath syncline and the Kingsdown anticline. Two smaller, satellite coalfields were also worked; the Severn Coalfield, in the Avon Mouth basin, lies five miles northwest of the city centre and runs under the Severn estuary to Portskewett. The Nailsea coalfield lies with a syncline seven miles west of the city centre. A small inlier of coal measures has also been worked at Clapton in Gordano.

These coalfields are rich in 18th- and early 19th-



Figure 4.2 This Newcomen engine house at Brislington, in the Bristol coalfield, has national significance as the UK's oldest intact engine house. It is mentioned in accounts of 1740 that confirm that the structure, which contained an engine with a 28" cylinder, was built c.1739. © Steve Grudgings

century remains and have been studied by the South Gloucestershire Mines Research Group and the Bristol Industrial Archaeological Society. As well as books (Anstie 1965; Cornwell 2001; 2003), there are papers in the *Journal of the Gloucestershire Society for Industrial Archaeology*, the *Proceedings of the Somerset Archaeological and Natural History Society* and the *Industrial Archaeology Review*.

To the south, the Bristol coalfield appears to have been left unworked in a syncline before re-emerging in North Somerset, where it was worked extensively. The Somerset coalfield is roughly rectangular, 12.8km long by 11.2km wide, and centred on Midsomer Norton, which has been subject to detailed studies by Gould (1999; see Section 4.8) but an early history was published by Down and Warrington (1971) (see also the Somerset Coal Canal below).

Kent

There was a small lignite mine at Cobham, near Rochester, which worked until 1953 (NMRS List of Coal Mines). Coal was discovered in 1890 during borings for a proposed Channel Tunnel, and development began in 1896 with the sinking of Dover, or Shakespeare, Colliery. Mining ended with the closure of Betteshanger Colliery in 1989. Kent was rare in having productive seams in the Upper Westphalian and is probably the only coalfield to have more suspended sinkings than working collieries. Scarcely any historical research on this coalfield has been published since A E Ritchie's tome of 1922, although, a recent monograph by Hollingsworth (2010) has covered much of the economical and social history of the area. A good source of information is Dover Museum's Coalfields Heritage Initiative Kent website,¹² which has a very informative education pack.

Lancashire and Greater Manchester

The northern part of the coalfield, between Colne and Blackburn, has a number of papers and monographs covering its history and geology, including works by Nadin, who has examined the mines of Nelson and Colne (Nadin 1996), East Lancashire (Nadin 1997), Accrington and Blackburn (Nadin 1999). A short report on Martholme Pit has been published by Bond (1984, 31-7) and Williamson has explored the Burnley Coalfield (Williamson 1999, 6-27).

The more important southern area, with its steeply dipping and heavily faulted seams, has not been covered in the same detail, although the Oldham area has been discussed by Fanning (2001). The Manchester coalfields were covered by Hayes (1987) and several collieries in the Worsley area have been researched by Atkinson (nd). Like parts of Staffordshire and Shropshire, the Wigan area produced large amounts of cannel coal,

which was favoured for gas making (Davies & Hudson 2001).

Leicestershire and South Derbyshire

The main coalfield lies in a ten mile square area centred on Ashby-de-la-Zouch in Leicestershire, extending across the county boundary into Derbyshire. There were probably small pits on Swannington Common before the Norman Conquest, where coal was regarded as a common asset of the free men of the village. Documentary references begin in the 13th century at Swannington and Worthington. There were mines at Staunton Harold in the early 14th century, and by the 1420s the nearby village of Overton Saucy was sufficiently well-known as a supplier of coal to be renamed "Coal Overton", later shortened to "Coleorton" (F Hartley *pers comm*)

A large opencast mine at Coleorton – the 'Lounge' Site - operating from 1988-1994 produced a wealth of evidence of earlier mining activities, particularly from the late 15th century, when well-organised pillar and stall mines were being accessed by timber-lined shafts at depths of 30m or more below the surface. There was also much evidence from the 16th century, and some items from more recent times. Hundreds of finds from this site were stored by the Leicestershire County Council Museums Service, mainly at Snibston Discovery Museum (see Section 4.8).

On the western side of the coalfield, mines at Swadlincote (in Derbyshire) are mentioned in 1294, and Leicester Abbey had mines at Oakthorpe probably in the 14th century, but certainly by 1477 (F Hartley *pers comm*). By this date there were probably also mines in the Derbyshire villages of Stanton and Newhall.

Mines were developed to gradually greater depths in the 16th, 17th and 18th centuries in the Swannington-Coleorton and Oakthorpe-Donisthorpe-Measham areas.

In the early 19th century, the Earl of Moira developed mines, an ironworks and a new settlement called Moira on the southern part of Ashby Wolds, served by the Ashby Canal. Between the 1820s and the end of the century, gradually deeper mines were sunk to concealed reserves south of the Eastern Basin, as far as Desford.

During the 19th and 20th centuries, most collieries set up an adjacent brick and tile works, and a network of railways evolved to link them to the national railway system. Ashby Wolds, an area of former open common land, between the Leicestershire and Derbyshire mines, became, in addition a major centre of sanitary ware manufacture.

In the late-19th and early-20th centuries, the area developed a pattern of settlement that is still obvious to this day, with scattered terraces of housing in and around the collieries, and ribbon development along roads from

village to village. The Burton and Ashby Light Railway, an electric tramway system, was constructed through Woodville and Swadlincote.

Twentieth-century developments were mainly concerned with linking existing mines underground, and improving surface handling facilities. Most of the 19th-century mines survived into the 1960s, before the rapid abandonment of deep mines in the 1970s and 1980s.

There is considerable evidence of coal mining in the form of earthworks around Coleorton, where five areas of pits have been scheduled as Ancient Monuments, with features probably dating from the 14th to the 17th centuries. A Newcomen engine house survives (much modified in recent times) at Moira, and there is a late 19th-century winder house at Calcutta Colliery in Swannington.

The buildings at Snibston, which are mainly of mid to late-20th-century date, but include some elements from the mid-19th century, form one of the best surviving groups of deep coal mine buildings still existing in the UK, and, until recently, were accessible to the public as part of the Snibston Museum site, now closed.

The Nottinghamshire coalfield (see below) has been traced across the boundary in Leicestershire, and in the 1980s it was proposed to sink new 'super' mines in the Vale of Belvoir. A mix of economic and political pressure meant that only one, at Asfordby, was allowed in 1986. This was at the southern edge of the coalfield and had significant geological and mining problems. In 1989, a Monopolies and Mergers Commission report on the British Coal Corporation noted 'we have been puzzled by the history of the Asfordby new mine project' and concluded that it 'has always been marginal in financial terms'.¹⁰

The history of the Leicestershire coalfield from 1200-1900 has been covered in considerable detail by Owen (1984) but for the 20th century and the complex story of the small pits, fireclay mines and potteries on Ashby Wolds, the coalfield lacks a comprehensive history and detailed, researched accounts for individual mines have not yet been attempted. A bibliography of papers and books on (mainly) geological aspects of the Leicestershire coalfield, produced by the British Geological Survey, is available on the web¹¹

Lincolnshire

A small and short-lived speculative coalfield sprang up in the Lincolnshire Wolds in the early-19th century, based around a misunderstanding of the local geology and the actual depth of the seams (Czajkowski 2000).

Northumberland

This coalfield has the widest geological range, with Namurian and Westphalian coals, but very little historical material has been published recently.

Geologically, Northumberland and Durham form one continuous exposed coalfield (the 'Great Northern Coalfield'); some sources treat this as one (Atkinson 1966), whereas others separate the two counties. For the combined coalfield, Hair (1844) forms an invaluable if, perhaps, over-used visual record of 1830s-40s collieries, and Atkinson (1966) is a relatively recent introduction. There have been papers in *Archaeologia Aeliana*, by The Society of Antiquaries of Newcastle upon Tyne, and the *Industrial Archaeology Review*. For Northumberland specifically, the recent literature includes Tuck (1993 and later volumes), Ayris & Vickerman (1978) and Bainbridge's volumes entitled *Coal Mines of North Northumberland* (1994; 1996).

Nottinghamshire

Unlike parts of South Yorkshire (see below) this area has very few workable coals above the Barnsley or 'Top Hard' coal. This results from a mixture of seam thinning and erosion. Nottinghamshire's coalfield comprises a thin band of territory on the extreme southwest of the county bordering Derbyshire. Although it is claimed that coal mining existed in Nottinghamshire as early as the Roman period, the *Historic Landscape Characterisation* for the county concluded that only late 19th and 20th century workings have made a notable impact on the landscape.⁸ The last colliery to produce coal in Nottinghamshire was at Thoresby, closed in 2015. Although there has been much historical research into the Nottinghamshire coalfield, most of the published material is now quite aged, and up to date material is scarce for this county. Early important papers include Bond (1924, 222-39) and Green (1935a

and b). Transport networks associated with coalfields have been researched by Hopkinson (1959, 22-41) and Stevenson (1969, 45-53). The most recent monographs are Griffin's *Mining in the East Midlands* (1971) and *The Nottinghamshire Coalfield* (1981). The same author has published a report on Brinsley Colliery (Griffin 1972, 28-47). Economic geography of the coalfield has been considered by Smith (1966, 235-41) and George (1993, 31-46). Additional, more peripheral material concerning the Nottinghamshire coalfield exists. A few pre-1998 papers on Nottinghamshire mining have been listed by Brook (Brook 2002), while Griffin (1981) gives an overview of the pre-nationalised industry there. A particularly useful source is on the Nottinghamshire Heritage Gateway website⁹, which includes a comprehensive bibliography for the historical study of coal mining in the county.

Shropshire

This county has a number of small coalfields. The Denbighshire coalfield runs into the northern part of the county and has been worked around St Martin's: there is an outlier near Oswestry. There are also small outliers of Westphalian strata around Westbury, Pontesbury, Hanwood-Shrewsbury, Wrentnall and Dryton

The Shropshire coalfield has benefitted from an active group of historical researchers and fieldworkers (see Section 4.8). There is a general summary of the county's mines by Pearce (1995) and a forthcoming volume will provide an account of the Shrewsbury coalfield (Shaw *forthcoming*). The main or east Shropshire coalfield, in the Ironbridge-Telford area, has received



Figure 4.3 Double headstocks at Clipstone Colliery, Nottinghamshire. Koepe Headgear and winder. © Ian Castledine

particular attention from Ivor Brown who has published some substantive accounts of collieries (Brown 1968; 2007) and a monograph on *The East Shropshire Coalfields* (Brown 1999), whereas the Cleve Hills and Wyre Forest (partly in Worcestershire) coalfields have been covered by others (Poyner & Evans 2000). Many small but important items of research have been published in the *Journal*, newsletter (*Below*) and *Accounts* of the Shropshire Caving and Mining Club and other mining history societies. The most authoritative historical study on the Cleve Hills Coalfield remains an unpublished PhD thesis of the late Ken Goodman (1978).

Staffordshire

Traditionally, this coalfield is treated as being in two main parts, a northern one around Stoke on Trent and a southern one around Cannock and the Birmingham conurbation, but modern geological knowledge shows it to be continuous through an unworked central area. The former area is also associated with two outlying coalfields to the east. One, a thin strip of coal measures, runs north-south around Shaffalong and had no modern mining. The other, a larger area, is centred on Cheadle and was worked until the 1990s.

This coalfield also lacks an up to date general study,

but a great deal of work has been done on a more site-specific scale. This includes a number of papers by Nigel Chapman discussing, for example, collieries at Heath (1994, 6-23); Bournehills (1995, 41-6); Blakeley Hall and Bromford (1996, 125-133); Sandwell Park (1997a) and several smaller articles (1983, 34-9; 1987, 35-43; 1997b, 93-6; 1997c, 156-61; 1999a, 56-63; 1999b, 64-73; 2000, 26-34; 2004, 47-57). Chapman has also published a more general monograph on *A History of Coal Mining Around Halesowen* (1999), as has Deakin (2004) for North Staffordshire, and Stone (2007) has produced a largely pictorial general history of the Staffordshire coalfield. The Cannock Chase Mining History Society has researched some mines in their area, including Lea Hall 1948-90 (Edwards & Warberton 2006), Brereton (Edwards 2005), and a general study of Cannock Chase (various 1990). Quarnford has been covered by Leach (1996). King (2007) has provided a detailed archive-based report covering the Black Country.

Warwickshire

This coalfield runs south from the very northern part of this county, around Polesworth, and contains Daw Mill Colliery, which closed in 2013 after a severe underground fire. The coalfield continues



Figure 4.4 Cobbs engine house, or Windmill End pumping station, Rowley Regis West Midlands. A rare survivor of the Black Country coal industry. © Ian Castledine

under Coventry and remains largely unworked. Like Leicestershire and Nottinghamshire, the coalfield in Warwickshire has drawn scant attention from historians, although aspects of individual collieries have been published including Hawksbury (Court 1937, 221-8). Grant (1978) has provided a historical account of Griff colliery in the 17th century and the Coventry to Nuneaton area has been covered by White (1970). A brief summary of the coalfield and its collieries, with short descriptions of what survives, has been provided by Chapman (2014).

Westmorland (modern Cumbria)

This area has a small outlier of Westphalian rocks, preserved by faulting, at Stainmore. Brooks has studied one of a number of small, Namurian coal pits (Brooks 2010).

Yorkshire, North

The history of the small, Ingleton coalfield is available as a monograph (Bentley et al. 2005). The Selby coalfield, Britain's newest, closed on October 26th 2004 when Riccall colliery stopped coaling. As yet, no complete history of this project has been written. Kellingley colliery, sunk between 1958 and 1962, remained in production until 2015.

Yorkshire, West & South

This region had large areas of coal, ironstone, fireclay and ganister mining. From the lowest seam (Halifax Soft Bed) to the highest (Shafton) there are some forty seams, all of which have been worked to some extent. Generally speaking, the lower seams have higher ranks (carbon content) and are more likely to be used as coking coals, whereas the higher ones are free-burning.

Ironstone occurs from Huddersfield to Bradford and on to Northeast Leeds and is intimately linked with the Better and Black Bed Coals. An extensive network of tramways and railways linked the pits to large iron works, especially at Low Moor and Bowling, near Bradford. Isolated pieces of archaeology remain between housing, industrial estates, etc.

Another important area of mining for coal measures (Tankersley) ironstone was around the village of Emley, in the south-eastern corner of the region. Some of these workings, which run into South Yorkshire, may be medieval, but most have the appearance of 18th-century remains.

A small area of the Lancashire coalfield extends into West Yorkshire and has been worked at Todmorden. Fireclay from this area, and from Halifax, was used for making sanitary ware, especially salt-glazed pipes, and

many collieries in the lower part of the middle coal measures, around Leeds and Wakefield, were associated with brickworks (see Section 6.2).

The switch from town gas to natural gas, the replacement of steam with diesel locomotives, clean air legislation and the change to generating electricity using oil or nuclear power in the late 1960s, reduced markets and forced the NCB to rationalise its mines. Many of the thinner seam mines were unsuitable for mechanisation, and the fairly high ash, sulphur or chlorine contents of lower coal measures seams meant that their coal was unacceptable to the large, coal-fired electricity stations. As a result a swathe of older, shallower West Yorkshire mines closed from the late 1960s and production was concentrated to the east of the M1.

Since the Second World War, large areas of mined landscape have been cleared for housing, industrial estates and motorways. Coal has also been extensively opencasted between Leeds and Wakefield, producing archaeologically barren landscapes, apart from the stark remains of the opencasts.

The last working colliery in this coalfield was Hatfield, which closed in 2015, as did Maltby in 2013 and a much smaller one (Hay Royds) near Huddersfield, in 2012. The *Gazetteer of British Coal Mines* lists some 1200 coal, clay and iron mines in West Yorkshire from 1854 onwards; to these must be added large (unknown) numbers of older pits.

As with other coalfields, various collections of photographs and reminiscences are available on the Internet. The *Yorkshire Archaeological Journal* contains a few papers on coal related matters, but apart from general memories of specific mines and strikes, the most recent general books are Goodchild's *West Yorkshire Coalfield* (Goodchild 2000) and Williams' (2005) *Images of Yorkshire Coal*. Hill's (2002) *The South Yorkshire Coalfield: A History and Development* gives a good general overview, with some detail (Gray 1976, 31-44). Over many years, John Goodchild has written about the various coal owning/working dynasties in this coalfield (Goodchild 2000). Henesey's paper on the Garforth area is also useful (Henesey 2010). There has been some private research, and at least one community archaeology report covering mining around Sheffield (Battye 2004; Kennett 2006). Medicott (1983) has published material on the Sheffield colliers, and Taylor (2001) has covered some of the South Yorkshire mines, as has Wain (2014). Historical research at various levels has been undertaken, focussing on individual collieries including Rowles' (1992) history of Birley East, and Fordham's works at Bentley (Fordham 2009a), Brodsworth (Fordham 2009b), Askern and Instonville (Fordham 2009c).

4.6 Technology

Coal mining can be seen as one end of a spectrum of overall mining technology, with copper, lead and tin at the other; the mining of a high-bulk, low-value seam mineral, as opposed to a low-bulk, high value vein deposit. While there are fundamental similarities between all mining technologies, and cross-adaptations and adaptations in both directions, there are also significant and consistent differences. Coal has tended to take the lead in bulk material-handling, notably rail transport, and in ventilation because explosive gas, which is rare in other types of mining, is present.

Substantial, and technologically advanced, coal mining can be identified from the later Middle Ages onwards, from historical evidence in County Durham, and from archaeological evidence in Leicestershire (Guy & Cranstone 2001; Hartley 1994, 91-101). That the latter was unexpected from the historical evidence emphasises the need for archaeological work to check, confirm and at times modify, or even refute, the conventional picture derived largely from (for the earlier periods particularly) a limited range of potentially selective and untypical historical sources. However, most of the available technological information is derived from 18th to 20th-century historical sources, which describe coal mines in use at that time and as this assessment is concerned with the full temporal range of this industry, the data for the later period are more detailed.

In the 17th century, technological advance was broadly centred on the development and spread of surface railed transport in order to meet demand by allowing the expansion of large-scale coal-mining into areas more remote from river and sea transport. Most notable were the wagonway systems which extended the workable 'Great Northern Coalfield' far into the hinterland of the Tyne, the Wear, and the smaller Northumberland coastal ports. Also, the Wollaton wagonway in Nottinghamshire, which was the earliest documented in the UK (1603 or 1604), though earlier examples may have existed in the Severn Gorge (P King *pers comm*).

The 18th century was marked by the development of the beam engine; the use of the Newcomen atmospheric engine for pumping allowed the working of deeper and wetter seams, and was centred in coal mining areas, where its high fuel consumption of small coal which would otherwise have gone to waste, was acceptable. The introduction of more advanced steam engines (Boulton and Watt and descendants) allowed still deeper and more powerful pumping, and the rotary motion necessary for direct steam-powered hauling. Not all coal fields adopted Boulton and Watt engines immediately on introduction, due to the cheap coal

outweighing the cost of the more efficient engines. However, miners paid a heavy price in the explosions, which became common as deeper and gassier seams became accessible. Inventions such as the steel mill for lighting, and ventilation by 'coursing the air' and later by furnace-ventilation, only partly mitigated the problems.

In the 19th century, the range and power of steam engines grew rapidly, and by the middle of the century the horizontal engine increasingly replaced the vertical-cylinder beam engine. Railway technology also developed rapidly, both on the surface and underground. From the middle of the century, fan ventilation developed, with an increasing range and power. Compressed air developed for underground use to power cutting equipment, and coal screening and washing led to the development of more complicated pithead layouts.

In the 20th century, electrical power replaced steam on the surface, and allowed increasingly mechanised extraction and transport underground, eventually with sophisticated mechanical coal-cutting, self-advancing roof supports, and armoured face conveyors. Screening and coal-washing also developed dramatically (stimulated by, and permitting, the switch in consumption from lump house coal to small coal for electricity generation). In the second half of the century, self-emptying skip hauling in shafts was gradually replaced by the use of conveyor-drifts, at shallow mines and seams, feeding via washeries into huge storage bunkers which in turn fed automated 'merry-go-round' trains to the power stations. These aspects of mining are examined below.

4.6.1 Prospecting

It is likely that the first coal seams were discovered by looking for outcrops in cliffs or river banks, or at the detritus from mole and rabbit holes. In order to trace and follow a seam across the landscape, however, it was necessary to dig trenches across the likely line of any outcrop. Extensions of the seams into a hillside could be found by sinking shafts. Though used in China several centuries before, the practice of boring for coal using long rods with a chisel end, is attributed to Huntington Beaumont, who first used the technique in England in the early-17th century (Smith 1957).

From the late-19th century a range of geophysical and chemical methods of prospecting began to appear. The former included resistivity and seismic surveying (Vernon 2008, 4-30). The recovery of borehole cores also became possible, as did later the geo-logging of boreholes. All of these techniques, ancient and modern, have left little known archaeological evidence.

4.6.2 Extracting coal

As with most forms of mineral extraction, early coal miners focussed on the most accessible, i.e. shallowest

deposits, which could be exploited with the least effort, and deeper seams were worked later as technology and knowhow improved. However, as so little archaeological evidence of the underground sections of early coal mines is available, the chronology of these developments is not particularly refined, and interpretation relies heavily on surface and documentary evidence.

Following discovery, extraction generally began along the outcrops of the seams, often in places which have long since lost their obvious link to the industry, and then migrated down dip, frequently necessitating deeper sinkings. An example of this is the Rivock Edge – Howden Gill outcrop, near Keighley, where most of the surviving evidence dates from the 17th century (Gill 2004c, 24-5). Where they survive, workings along a seam outcrop of this type show that a range of techniques might be used, including a small amount of opencasting (the modern process would remove all traces), drifts (see below), and shallow shafts. The latter are often referred to as bell pits and history books have a range of explanations as to how this name originated and what it represents, which is generally just a very rudimentary form of mining.

A bell pit is a shallow shaft which ‘bells out’ at the bottom to extract as much of the seam as possible over a relatively small area. Work would continue

until flooding, lack of ventilation, or the danger of collapse necessitated abandonment of a shaft and commencement of another nearby. Sinking-dirt and other spoil could be used to backfill the neighbouring, abandoned pits so, at the surface, this was likely to produce a cluster of shallow hollows surrounded by minimal amounts of spoil. Weathering, ploughing or land improvement may have obliterated all obvious traces of such slight features.

The use of the term ‘bell pit’ is subject to heated debate. The main problem is that an earthwork feature is often described as a bell pit based only on surface evidence of a spoil heap with a central backfilled shaft, without consideration of what lies below ground. However, such evidence could represent a number of underground techniques, which were well in advance of the crude, small-scale, unsupported affairs implied by the term bell pit. To avoid misinterpretation, some mining historians and archaeologists now tend to replace bell pit with the term shallow shaft, which has its own issues, not least the definition of shallow (up to around 100ft or 30m). Establishing the true nature of these remains will be problematical until additional underground evidence is recorded. This will be achieved with difficulty because of the constraints associated with exploring coal mines underground.



Figure 4.5 Aerial view showing surface evidence of coal extraction using shallow shafts at Titterstone Clee in Shropshire.
© Clwyd Powys Trust

Other productive, and slightly more enduring, means of extracting coal underground are the 'pillar and stall' (sometimes referred to as room and pillar) and 'longwall' techniques, both of which may be served by shafts with similar surface remains to the bell pits. Using the former method, the seam was worked laterally by driving headings and cross-headings to create rooms or 'stalls', but sections or 'pillars' were left in place between them to support the hanging wall (roof). When the boundary of the seam was reached the pillars were often removed as work retreated, though less so in earlier mines.

Longwall working involves tackling a seam by establishing a linear 'coalface' whereby a long edge section of the seam may be removed laterally as a continuous operation. As work progresses, the roof of the worked areas, behind the workers at the coal face, is supported by artificial props, usually of timber, though in modern mines hydraulic supports are employed.

Pillar and stall was the earlier of the two methods to be developed and was certainly in use by the 15th century. Longwall workings, although traditionally assumed to be much later, have been found to have been in use in the early 16th century in Leicestershire (Hartley 1994, 94). Both methods have survived and been adapted to the modern highly mechanised systems in use in the present day in various parts of the world. Hatcher has sounded a note of caution when using these terms, claiming they are too prescriptive and don't accurately reflect the vast differences in

coal working techniques, which were dictated more by geological condition and available resources than tradition or precedent (Hatcher 1993, 201).

Very shallow pillar and stall workings have been noted in the Peak District where, in a few places, there are also workings with very close spaced opencast pits and shafts adjacent to outcrops (J Barnatt *pers comm*). These may represent multi-phased, early ad-hoc extraction. However, in many other cases, very shallow mining is found in the context of soughs (see below) driven in the seam, which was then worked up dip but stopping short of surface to avoid the drainage problems of peat ground. Where dating evidence exists, these workings, which have regularly spaced shafts only tens of metres apart, are often of 17th to 19th century origin. Earlier workings are very restricted in location and lateral spread, which may reflect medieval working and/or a transition to the other method as the discovery was assessed and found to be workable. While some regularly-spaced shafts to pillar and stall are spaced commonly in the 20-30m range, many are significantly less.

There is a photograph of small-scale, roughly-circular coal workings, uncovered by more recent opencasting at Stretton in Derbyshire, but most bell pits which have been studied were associated with ironstone mining (Griffin 1971, 20). Several 'belled' features, which are at the foot of an obvious shaft, at the horizon of the ironstone immediately above the Little Ryhope Coal, were recorded at Craghead, near Edmondsley in Co.



Figure 4.6 Vestigial remains of early underground coal working at Sharlston near Wakefield, exposed during opencast operations. © OAN

Durham (Hedley 1995). At no point, however, had these workings penetrated the coal. Similar 'belled' features were seen between the shafts, but with no shaft. They were interpreted as being the front or rear parts of the bell associated with either an intended shaft which had not been cut, or one that had been destroyed. Nevertheless, because the cover was not stripped off to allow the plan of any workings to be seen, they could equally represent the ends of stalls or banks from a more complex system of working.

Shaft sinking

Once found, the coal could be worked opencast along the outcrop, but the increasing depth of overburden usually meant that the seam was followed underground. At early extractive sites, this would be done from shallow shafts and, particularly where drainage was needed, drifts or day holes. Where deeper access was required, more substantial and enduring shafts were needed.

Where the coal remained fairly shallow, it was usual to sink new shafts as the workings progressed. This had the advantage of aiding ventilation, but primarily it cut down the distance that coal was hauled from the face to the pit bottom. This has left distinctive landscapes, with rows of fairly regularly spaced shafts forming a grid, which until the mid 19th century were known collectively as collieries.

Timber-lined shafts are either square or rectangular; the medieval examples revealed at Coleorton were 3-5ft (0.9-1.52m) square with mortise and tenon main frames (Hartley 1994, 91). Later, circular shafts were lined with stone or brick, although they were often left unlined when they passed through competent strata. In some areas the bricks were laid without mortar in order that they could be recovered for reuse. By the late-19th century, cast-in-situ concrete linings were introduced. As collieries increased in size and depth, shafts were sunk at larger diameters (seldom more than 25ft (7.6m)) to allow larger cages or skips to be used for winding. Nevertheless, many shafts were less than 10ft (3m) in diameter.

As shafts became deeper, it was often necessary to sink through soft ground or aquifers and a range of techniques were developed to do this. Near the surface interlocking piles might be driven down to the rock head, but this method was probably limited to the first 100ft (30m) or so. After that, iron tubing or an open caisson could be used to get through flooded or soft strata. As the caisson was undermined it would sink, and new sections were fixed on top until solid ground was reached.

The first successful method for boring shafts through heavily watered strata was developed by Kind.

It relied on tubing to support the shaft sides and used a large trepanner to bore the shaft. Kind's initial attempt to sink a shaft in Belgium failed, but M J Chaudron redesigned and greatly strengthened the tubing and made the trepanner much heavier. However, as the Kind-Chaudron system, this method proved its worth and was dominant from 1852 until the early 1900s, when grouting and freezing made it obsolete. The system was first used in England to sink Littleton colliery, Cannock.

Where the strata were fissured and flooded it was possible to inject concrete in order to make a solid, dry area through which the shaft could be sunk. However, for much of the 20th century, it became usual to sink boreholes around the area of the proposed shaft(s) and pump near freezing brine through them; eventually this froze the area solid and meant that shaft sinking could proceed as if there was no water.

Some collieries in the Peak District and Yorkshire Dales worked under extensive areas of peat, where it was necessary to construct causeways across bogs to serve individual shafts. The procedure used to sink a shaft through peat has not been studied, but in some cases catch-water drains were dug on the upslope side of shafts to keep surface water out.

As collieries became deeper, or multiple seams were worked at once, it became more cost effective to sink a central mine and work out from it. This was especially important where surface facilities, such as a railway or canal, were involved. Additional pits might then be sunk some moderate distance away in order to improve ventilation, provide pumping, or for coal winding. In some cases the whole operation might eventually migrate to the remote pit. An example of this is Daw Mill (closed in 2013), sunk between 1957 and 1959 as a satellite shaft for Dexter colliery, itself a satellite of Kingsbury Colliery.

Drifts and slants

Where mines were troubled with water, or the coal outcropped on a hillside, drifts, which rose at a slight gradient, were driven into the slope in order to work and drain the working area. A variety of local names for these workings includes: level, sough, adit, day hole, drift, waterloose and footrill.

As well as draining water from the mine, which was cheaper than pumping, graded drifts allowed the use of railways/tramways directly from the face to the surface and could use gravity to assist in the movement of the materials. Inclined drifts, dips or slants, were used to get at shallower seams especially after the introduction of wire rope in the late 1830s. The method was used earlier, however; and, near Padiham on the northern edge of the Lancashire coalfield, historians are discovering traces of a coal mining complex which used a waterwheel for

pumping and winding from inclined drifts in the 18th and early-19th centuries (Jefferys & Mathews 2008).

Where workings met water, adits (soughs or waterlooses) were driven, from a lower point on the surface, at a slight upward gradient until they intercepted the seam and drained it. Examples of this practice are known from medieval Derbyshire (Guy & Cranstone 2001, 34), and early-modern Black Country mines (King 2007). Adits might also have later been used to drain water pumped from deeper workings. In the late-19th and 20th centuries mine owners often cooperated in drainage schemes in which water from a number of mines was channelled through dedicated water gates to a central pumping station.

The increasing use of conveyor belts in the 1960s meant that drift mines became even more efficient and at many collieries drifts were driven to replace shafts.

Another important method of working, seen in the Peak District often at greater depths, involved driving soughs (in two cases used as canals) in the seam, which in some situations was accessed by cross-measure drifts. Fewer shafts were needed and they were only used for ventilation, unless, as at Thatch Marsh (see below) after the canal had collapsed, for steam-powered winding.

Breaking the ground

Fire Setting

This method of using fires, burning wood or coal, to break or soften hard rock, which could then be removed using crowbars, hammers and picks, was common in metal mines during the 16th and 17th centuries (Barnatt & Worthington 2006b) and was probably first used in the prehistoric period. Writing in 1556, Agricola described it as an ancient technique (Agricola 1556). Obviously in coal mines it was used for breaking through country rock rather than the coal itself, to which the following example testifies. In 1706 at Colsterdale Colliery, near Masham, a shaft was being sunk which had hit a bed of hard sandstone and the agent, John Robinson, wrote to Sir Abstrupus Danby that:

I stay here to Sett a fire of wood and coals in your sinking pit which is so ill to blast or cut with picks I hope it will tender and open ye joints that spends all ye powder to no purpose (Tyson 2007).

Unfortunately, such references are rare, and the lack of archaeological exploration underground has so far provided no evidence for this practice.

Blasting

The development of explosives as a useful force in metal mining was underway by the mid-17th century and is discussed elsewhere in this report. Its use in coal mines, if not contemporaneous, followed shortly afterwards.

In Yorkshire, Abstrupus Danby made an agreement on October 4th 1690 with Edward Hodgekinson, Robert Archdale and Peter Smith, all miners of Pateley Bridge, to drive a level at his Colsterdale Colliery. 'They were to find at their own charge all tools, workgear, Gunpowder, except iron, steel and boards,' which Danby was to provide (Tyson 2007, 34).

According to the Chirk and Powis manuscripts, Sir R. Middleton's miners used gunpowder at the Carreghofa mine in 1692 (Lewis 1967) – its first known use in Wales.

The use of high-explosives in longer shotholes, began to displace gunpowder. This process was encouraged when sheathed, or flameless, explosives were developed. Nevertheless, while it was increasingly replaced by high explosives, gunpowder was still used for blasting in the early 1950s, and probably later in non-flamelamp (safety lamp) mines.

Opencasts

Since the beginnings of mining, some coal has been worked opencast, but it was developed on a large scale as an emergency wartime measure by the Ministry of Fuel and Power from 1942. Except in those areas where coal was alienated (sold back to the original owners) under the 1938 Act and working was controlled by planning authorities, responsibility passed to the NCB in April 1952. Since 1995 it has rested with the Coal Authority.

Opencasting was usually undertaken by contractors who operated a range of large earth-moving plant for stripping and moving overburden. Where a single seam was being worked, this was usually placed behind the working face, so that the excavation resembled a cutting moving sideways. At some sites the overburden was stripped by large, walking draglines, which steadily dug the overburden and deposited it where smaller machines could load it into dump trucks for removal. Modern opencasts tend to be much deeper, however, and work a series of seams, each with its own bench. This requires the total removal of overburden until the final landscaping phase begins. In this case, large 360-degree hydraulic excavators are used to load massive dump trucks. The coal seam is then exposed by smaller machines and any rock etc, removed in order that a very clean product can be sent from the mine.

Where seams have already been mined using partial extraction techniques, like pillar and stall or bank work, archaeological examination of exposed workings in more recent opencasts has provided valuable knowledge (see Section 4.8). However, if a seam has been worked longwall, it is unlikely that much information will be recovered, apart from packing techniques.

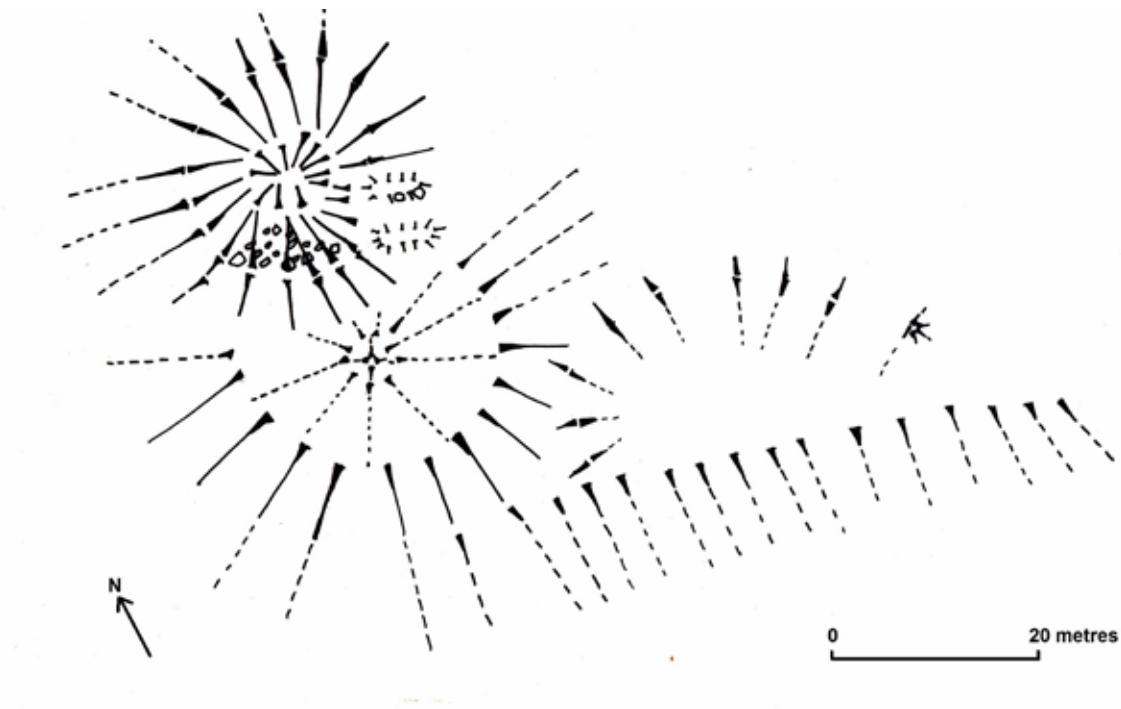


Figure 4.7 Earthwork plan of a horse whim platform at Bordley, North Yorkshire. Bordley Township Project

4.6.3 Winding

On shallow shafts of the type used at early coal extraction sites, a jackroll, or windlass, was used to lift coal or rock in a small kibble. This technology is known to have survived at small-scale operations into the 19th century, but as shafts progressed to depths significantly beyond 100 feet, they were increasingly wound by horse gins or whims lifting larger kibbles. Some collieries used waterwheels for winding and a few used water balance systems. In the 18th century, the reciprocating action of a steam engine was applied to winding drums. Various arrangements were favoured over time, with flat ropes winding onto a cage, or tapered hemp ropes or chains onto a cylindrical drum. By the late 18th century powerful, horizontal, condensing steam engines with wire ropes and conical drums had become the norm for deep shafts. Flat ropes, made by stitching a number of round ones together, were used at the Duke of Norfolk's collieries in Sheffield by John Curr in 1798 (Patent No.2272, 17/11/1798).

A German system of winding, invented by Carl Friedrich Koepe in 1876/1877, used a continuous rope running from the top of one cage, over a shaft-head pulley, around a cylindrical, wood-lagged drum (with one or two laps), then back over a second shaft head pulley and down the shaft to the top of the other cage.

Another continuous rope linked the cage bottoms and ran around a pulley in the sump. The friction drive allowed for much higher winding speeds and the use of lighter ropes. It is used in modern lift systems as well as in mines. Koepe's first patent had the winder at ground level and close to the headgear, giving the ropes a very steep angle of ascent. Shafts sunk, or modernised, between the 1950s and the 1980s, especially where skip winding was used, were often fitted with powerful electric winders using Koepe's system. The system's advantage was that it was much more efficient, typically using between 25% and 30% less electricity, and it used less winding rope. This needed to be changed at two year intervals, however, rather than the usual three years.

A development of Koepe's system was the Koepe tower, in which the electric winding mechanism was placed at the top of a substantial tower, directly over the shaft. Although adopted more slowly in the UK, the first was installed at Plenmeller Colliery, near Haltwhistle in Northumberland, in 1914, and most of the major coalfields eventually had examples of them. Until recently they could still be seen at Kellingley, Maltby and Harworth Collieries, but all will soon be effaced following their closures. Conservation work was undertaken on the example at Murton (Ayris 1994) now obliterated.



Figure 4.8 Unusual headgear built into brick tower at Western Fan shaft, Western Derbyshire. © Ian Castledine

4.6.4 Pumping

At first, water might be baled from shafts using buckets on ropes, but, as well as indications of late-medieval coal mining, Moorhouse Woods near Durham is the site of the earliest (1486-87) recorded use of horse-powered pumps (Raine 1837); these were of unknown type, but in the 16th century horse gins were adapted to drive 'rag and chain pumps'. By the 18th century water wheels were also being used for pumping and winding from shafts. The importance of these wheels has been eclipsed by the steam engines, but their presence is known by remains of water courses at Vobster, in Mendip (Gould 1996, 14-26), at coal mills on Tyneside (Clavering 1994, 124-32), and by a wheel pit at Read in Lancashire (Jeffery & Mathews 2008).

The introduction of Newcomen's atmospheric engine in 1712 meant that massive, masonry engine houses quickly appeared on many coal pits. These, and later Watt or Cornish, engines were principally used for pumping, but during the 19th century an increasing number of horizontal, winding engines were employed on collieries. At deep shafts, many of these were compound engines, which required large houses, but some areas preferred a vertical cylinder, to drive a winding drum through a crank mechanism vertically above it. The latter houses were much smaller in plan, but often three storeys high. Most coalfields, including the non-Westphalian ones, have examples of engine houses, but Somerset and Bristol has more than most, including at Nailsea (Morris 1996). Good examples also survive in Shropshire, at Muxton Bridge and others (Pearce 1995, 40). In cases where the house has been

demolished, there is a good chance that the even more massive foundations, or bed, for the engine remain. No major study or typology of colliery mine engine houses is known, but Bick wrote of some Welsh examples (Bick 1989, 84-93).

All steam engines needed a boiler house, the size of which varied to suit the engine. Early engines used haystack boilers, which were like a large kettle supported over a fire. In 1812, Trevithick developed the Cornish boiler, which was cylindrical with a single fire-tube. Such boilers were suitable for pumping engines that made comparatively small demands for steam. Fairbairn's introduction of the Lancashire boiler in 1844, with its double fire tubes, was well suited to the much greater demand for steam made by the large winding and textile engines then being developed.

Boiler houses tend to be fairly lightweight constructions, in order to allow replacement of boilers, and chimneys are the most likely survival. Nevertheless, the masonry seatings for boilers and their blow-down drains may still survive. An egg-ended boiler working from 1843 to 1869, is still on site at Engine Pit in Colsterdale (Tyson 2007), and a range of Lancashire boilers survive *in situ* at Chatterley Whitfield near Stoke.

4.6.5 Ventilation

It was necessary to provide a flow of fresh air through a colliery in order to clear methane, carbon dioxide and air-borne dust from the workings, as well as maintaining a reasonable working temperature and humidity (Hill 2000). Rock temperature always increases with depth, and Britain has one of the world's highest geothermal gradients.



Figure 4.9 Newcomen engine house at Elsecar Yorkshire which still contains the engine for which it was originally built. © Ian Castledine

Furnaces

Small mines, especially those with a shaft and an adit, often managed with natural ventilation, where warm air rose up the shaft and drew fresh air into the adit. Such a system might be enhanced by hanging a firebasket in a shaft, especially where the problem was carbon dioxide. This evolved into a furnace, with a tall chimney, near the shaft top. From the 1780s, larger mines increasingly had furnaces at the foot of an upcast shaft, in order to create a rising column of warm air. This was more efficient, but had obvious hazards in terms of methane explosions and their use at mines employing more than thirty persons, or in gaseous seams, was discouraged by the 1911 Act. New installations were not allowed in larger collieries from that date, but some existing furnaces (e.g. Walsall Colliery) continued in use until the 1950s at least.

Fans

A variety of mechanical devices were tried, but from the 1830s a range of fans was designed specifically for the task. Probably the most widely used type was by Guibal, a Belgian civil engineer, but in the 20th century Sirocco fans also became common. Although fans were more expensive to install than furnaces, they were much safer and cheaper to run. Their speed and the volume of air moved could also be regulated, or even reversed. Too large an air flow could encourage spontaneous combustion in some seams.

Some are set over upcast shafts, with the area around the shaft totally enclosed with a mixture of masonry and a metal box structure, with air locks. There

will also be traces of ductwork running from the fan to the shaft top (e.g. Grange or Monckton Main). Traces of fans and their engines also survive. There was a Guibal fan at Mackintosh Colliery in Somerset where partial remains of the stone-built fan house survive (Gould 1996, 16-26), and more modern ones at Clipstone and Chatterley Whitfield.

Upcast shafts with furnaces often had a cupola or chimney over them to improve air flow. A survival, converted to a dwelling, has tentatively been identified at Whaley Bridge (Leech 1992).

A definite survival is the ventilation chimney at Golden Valley Colliery, Bitton near Bristol (J Fussell *pers comm*). A complete ventilation furnace remains at the entrance to a drift in Beathall Woods, at Ironbridge, but the iron chimney has been removed and is being used nearby as a culvert (I Brown *pers comm*). The furnace pit at Caphouse has been repaired and, while it lacks a chimney, it is proposed to include the bottom of it in the underground tour.

4.6.6 Transport

At the earliest sites, coal was moved using pack-horses or carts, and spoil was dumped into heaps using wheelbarrows. Early mines may exhibit traces of hollow-ways, or sunken tracks, which served them. There are such tracks around Thorpe Fell colliery, near Grassington, and at various mines above Buxton. At small coal pits, the material brought up the shaft was transported by sledge (marks left by their use have been recorded) or wheelbarrow; where the coal was brought up the shaft in baskets, called corves, these were detached from the rope and loaded onto trolleys or sledges. Mines in areas of peat were served by distinctive pavements running to each pit. Good examples have been recorded at Goyt's Moss and Tan Hill collieries (Barnatt & Leach 1997, 56-80; Tyson *forthcoming*).

Many collieries were associated with canals or railways, some of which were pioneering developments. More than any other industry, coal may be credited with being one of the greatest influences on the development of transport networks in England.

Canals

The first manmade waterway, the Bridgewater Canal, opened in 1761. It was designed by Brindley, and dug specifically to provide haulage of coal from the mines at Worsley to Manchester's industrial areas; it provided a model for future canal projects. Horizontal canal tunnels allowed bulk loads to be carried directly from the interior of the mine. Other contemporary examples of this system were installed at Thatch Marsh and



Figure 4.10 Reconstructed colliery wagon at Silkstone.
© Ian Castledine

Blackclough near Buxton. In the 1790s the Somerset Coal Canal was conceived to provide a means of shipment, in conjunction with a system of tramways, for a number of separate collieries in the North Somerset coalfield (Chapman 1987a & b).

Tramways, wagonways and railways

Although, now an important part of modern life, years before rail passenger transport was conceived, railways were developed for hauling coal and iron. Their first recorded use was in 1603-4, when Huntingdon Beaumont built the Wollaton Wagonway from Stalley to Wollaton, at Nottingham (Lewis 1970).

The wooden rails used on early wagonways soon deteriorated and, in the later 18th century, engineers sought to replace wood with cast iron. One of the first to do so was Richard Reynolds, manager of the Coalbrookdale Works in Shropshire, who, in 1767, replaced the wooden rails used around the company's works and mines, with iron (Day & McNiel 2002, 1034). Advances were also made underground at Sheffield Park Colliery when, in 1787, John Curr replaced earlier wagonways that used beech rails, with 'L' – shape, cast-iron plates (Mott, 1969, 4; Medlicot 1983, 51-60).

Next came William Jessop who, in 1789, used fish-bellied cast-iron edge rails, with flanged wheels, on a horse-drawn railway for coal wagons at Loughborough. In the following year, Jessop went into partnership with Benjamin Outram and two others to form what became the Butterley Iron Works, for manufacturing iron rails. Outram, on the other hand, favoured L-shaped iron plate-rails; in 1793, he used them on a tramway that ran from Bullbridge Wharf on the Cromford Canal to a limestone quarry at Crich, in Derbyshire (Hylton 2007). This line was a little over a mile long with a gauge of 3

feet 6 inches, but Outram soon settled on a 4 feet 2 inch gauge for later lines.

Outram described his lines as 'railways', but the term 'tramway' (or 'tramroad') was already in widespread use and it came into general use for lines using his flanged rails. The term 'railway' was more widely used after the opening of the Liverpool and Manchester Railway in 1830, which used steam locomotives running on edge rails. Thereafter, the 'tramway' (or 'tramroad'), with L-shaped rails, and 'railway', using edge rails, were used to describe two distinct modes of rail transport. Within the Lancashire coalfield, many of the small mines were linked by chain hauled tramways locally called 'ginneys.'

Some surface tramways continued working until the early 20th century, but many small mines, especially those working thin seams, used them until the 1960s. Edge rails were also extensively used underground, carrying tubs with capacities ranging from 10 cwts (508kg) to mine cars of up to 5 tons.

Complex tub circuits were laid out at the pit bottom and top, for taking full wagons to tipplers, where they were emptied, and returning empty ones to the shaft.

Richard Trevithick is credited with designing the first viable steam locomotive, which in February 1804, hauled 10 tons of iron, seventy passengers and five wagons from the ironworks at Penydarren for 9 miles to the Merthyr-Cardiff Canal (Rattenbury & Lewis 2004). Unfortunately, the heavy loco broke the rails and the project was soon abandoned. Trevithick later visited Tyneside to build an engine for a colliery there.

The Middleton Railway, a private, horse-drawn colliery line near Leeds, was the world's first railway line to be authorised by an Act of Parliament in 1758, when it was extended from the colliery to Staithe near Leeds Bridge. Faced with a shortage of horses during the Napoleonic Wars, John Blenkinsop, the colliery manager, worked with local engineering firms to build a steam locomotive in 1812. The resulting loco, called *Prince Regent*, worked on a rack and pinion system developed to cope with steep gradients, and was soon joined by a second loco, named *Salamanca*. Leeds went on to build more locomotives than any other centre in the UK. Similarly, the Lake Lock Rail Road Company, formed in 1796, opened what was arguably the world's first public railway, to the northwest of Wakefield, because it served more than one colliery owner and also carried goods for all comers.

Long before the Rainhill trials of 1829, George Stephenson, no doubt inspired by Trevithick's efforts, designed his first locomotive, with flanged wheels, named *Blucher*. In 1814, it hauled 30 tons of coal up a hill at 4mph on the Killingworth wagonway. Many of these early locomotives had problems with being under-boilered, or with breaking the cast iron rails then

being used. William Losh, a local iron master, worked with Stephenson to overcome the latter problem, but it was not solved until much later, with the introduction of rolled steel rails.

Work began on the Stockton and Darlington Railway in 1821 under the supervision of George Stephenson, and his son Robert, who had persuaded the proprietors to abandon their original plan of using horses to draw coal carts on metal rails, in favour of locomotives. The 25-mile railway connected various collieries near Bishop Auckland and passed through Darlington on the way to the River Tees at Stockton. A useful contemporary account of this railway exists, and of others of the period, including that from Hetton Colliery to Sunderland, by the Prussian mining engineers Von Oeynhausen and Von Dechen (Forward 1971).

As the national railway network grew in the 19th century, many collieries had extensive sidings on which trains could be assembled. The wagons were loaded by parking them under the screens to receive a particular grade of coal.

In order to serve the electricity generating stations more efficiently, many NCB collieries with rail links were fitted with Rapid Loading Bunkers from 1965. Coal from the washery was loaded by conveyor belt into the bunker, which stood astride a specially graded section of railway track. The non-stop merry-go-round train, of thirty or so top-loading and bottom-emptying, 33-tonne wagons, would be hauled under the bunker by a loco fitted with a slow-speed control, which allowed it to move at about 0.5 miles per hour. Once loaded it was off to the power station, where it was automatically unloaded while on the move.

From the late 18th century, ponies were used to pull trains of wagons underground, but from the 1850s compressed air, and then electric motors, were used to drive endless rope, or main and tail, haulages on main routes (Brown 1989, 78-88). Haulages were also driven by endless power ropes that ran from an engine at the surface, either down the shaft or along a drift. This had a circular wire rope, running on pulleys and round a drive drum, to which trains of wagons could be lashed, clamped or clipped. Smaller haulages, with a single rope, were used locally within the mine.

However, fixed haulage systems did not give the flexibility of horses, so efforts were made to develop locomotives that were safe for use in collieries. A 10-ton battery locomotive is said to have been experimented with at Tilmanstone Colliery in Kent, in 1922 (Hill 1991; Report of H.M. Chief Inspector of Mines for the years 1939-46, 25). The first diesel locomotive used underground was at Kingshill No.1 Colliery, near Cambusnethan in Ayresshire, Scotland, in 1935 (Oglethorpe 2006, 196-7). In 1939 the first 'flameproof' locomotives in England were used underground at



Figure 4.11 Section of disused colliery railway, Butterly, near Ripley in Derbyshire. © Ian Castledine

Rossington and Bentley collieries near Doncaster, which were both safety lamp mines.

Ropeways

Although there had been earlier attempts to make a functioning aerial ropeway, the first patent for a monicable ropeway was granted to Henry Robinson in 1857 (Patent No.1786, AD1856). He was described as a coal agent from Settle, in Yorkshire, but he also had a limestone quarry at Ingleton (Johnson 2010a). His system used an endless rope, supported at intervals by pulleys mounted on posts or pillars. At either end the rope passed around larger pulleys, one of which was driven by a power source. Loads were suspended at intervals from the rope. The last ropeway of this type, at Cloughton brickworks near Hornby in Lancashire, worked until early 2010¹³.

An 'improved' ropeway was designed by Charles Hodgson, of Richmond in Surrey, in 1868 (Patent No.2281, AD1868). This had a fixed, endless rope, on which the loads ran, suspended from pulleys. A second rope, which linked the buckets, was used to haul them.

Ropeways of both types found favour at quarries and mines, and were generally used at collieries for taking spoil from the screens/washery to the waste heap as at the infamous Easington and Blackhall colliery sea dumps in County Durham, featured at the end of the 1971 film *Get Carter*. Many ropeways were replaced by conveyors or dump trucks from the later 1960s.

4.6.7 Sources of power

Like metal mines, the advancement of underground technology in the coal industry depended on the introduction and adaptation of new forms of power. The man-powered windlass and the horse whim or gin for raising materials and water; then water power followed

by steam power for pumping and hoisting. Finally, by the 20th century, electricity and compressed air were the norm for powering equipment underground.

Endless power ropes, running down shafts from an engine at the surface, were used to drive main haulages, but could also drive fans or pumps at a distance from the pit bottom.

Many late-19th- and 20th-century collieries used compressed air to provide power underground. This required a number of stationary compressors, driven by electric motors or steam, in a surface power house. Nearby would be a bank of air receivers (often converted boilers), which provided a reservoir of air. The air was then taken underground in large steel pipes, called ranges, and split between the districts.

The first use of electricity in an English coal mine is uncertain, but it is thought to be at Trafalgar Colliery, in the Forest of Dean, where a small electric pump was installed in the early 1880s (Hill 2011). As already noted, Pleasley Colliery used electricity to light its pit bottom around that time.

In pre National Grid times, collieries often generated their own electricity in power houses. After linking to the National Grid, mines would have transformer substations. Power houses might also contain a number of compressors and receivers for supplying the mine's compressed air needs.

4.6.8 Drills, air-picks and mechanised cutters

Until the late-19th century, shotholes were drilled by hand using a long chisel, which was hit by a heavy hammer. Various mines experimented with compressed air drilling from the 1870s, but the drive for this came from civil engineering tunnel work. However, the early machines were both bulky and heavy, and their use tended to be restricted to driving levels. In mines with soft rocks, like shale or coal, the rotary hand drill found favour because it was much lighter. In these the rotary action of a handle was converted, through gearing, at right angles to drive a twist drill. Such drills were better suited than percussive drills to boring in coal and softer strata.

Improvements to compressed air drills in the early 20th century made them much lighter and more reliable (Chapman 1993, 104-27). Moreover, advances in electrical power meant that hand-held borers were widely introduced on coal faces.

Coal cutters were often driven by compressed air, especially in gaseous workings. Such machines demonstrated a rule of physics, whereby a rapidly expanding gas produces a cooling effect. This gave problems in high-temperature-humidity workings,

where the exhaust produced mist and seriously reduced visibility on the return side of the machine. Ice also tended to accumulate on the exhaust and sometimes choked it.

In the late 18th century, it was realised that the mechanisation of coal cutting had the potential to reduce labour costs significantly. Early attempts often mimicked the picking action of a collier, but lacked a suitable source of power. An early example in Shropshire failed because it could not compete with manpower, and the men were not prepared to use it. One of the first viable machines, driven by compressed air, was introduced at West Ardsley Colliery, near Leeds, in 1861 (Gill 2009, 116-23).

Pre-1960s references to coal being cut by machine usually refer to undercutting, where the coal was subsequently brought down by blasting or wedges and loaded by hand. In 1945, for example, 28% of all coal worked was still undercut by hand; this produced lump coal, giving the (then) best price.

4.7 Coal preparation

When coal was cut by hand the colliers were fined for sending out too much dirt or fine coal, but machine cutting of coal meant that some means had to be found for removing rock from in-seam dirt bands, pyrites etc. The larger pieces could be seen and removed on a picking belt prior to screening into a range of sizes. This was done in a metal framed or brick vaulted building, which stood over a series of parallel railway tracks. The screened coal dropped, via chutes, straight into wagons.

The washing and separation of small coal was pioneered in Germany, by the likes of Lührig and Baum, in the late 19th century. They developed what dressers at metal mines would recognise as jigs, and called them wash boxes. At first their capacity was limited to a few tons per hour, but around 1900 Baum developed a washer, which used compressed air to aid separation and increased the through-put to nearer 100 tons per hour. From the 1920s, Baum washeries became standard at most British collieries. Typically they are characterised by their mass-concrete elevated, conical settlement tank, which was almost the same height as the washery building.

4.7.1 Coke

Frequently, the production of coke occurred at or near the pithead, and has provided a wealth of material remains. By the mid-17th century, coke was being made using the charcoal burner's practice of covering a heap of coal with earth (a meiler), and roasting it by controlled combustion, when its use was recorded for providing heat for malting, lead smelting and alum

calcining (Beaver 1951, 133-48). This process was replaced after the introduction of Beehive coke ovens, which were first recorded in the Newcastle area and Cumbria in the 1760s. These were non-recovery type ovens, in which the coal charge did not fill the oven. Space was left above the charge in which the gas and other volatile matter liberated from the coal was burned. Jars describes three banks of three ovens, of around 3ft (0.9m) diameter with a loading door and a steep conical vault leading to a small top opening (Jars 1774, 209-11; 365-6; Pl 9). By the late 1760s, or early 1770s, banks of up to six ovens were being built, and a diameter of about 9ft (2.7m) was considered normal (NRO 3410/Wat/2/10, 229); these ovens had iron doors, but there is no mention of any top opening.

In the 1890s, more complex coking plants began to appear. In these, gases were captured and piped away for condensation into tar, sulphuric acid and ammonia. The remaining gas was then either burnt as part of the process or sold into the town gas supply. Such modern ovens were larger and, to increase their capacity and efficiency, had automated charging and discharging.

Beehive and other types of coke ovens survive in various places in England including scheduled examples at Fountains Fell (SM 29531) in the Yorkshire Dales, Tow Law (SM 30929) (which has been archaeologically excavated), Hedleyhill Colliery (SM 30931) County Durham, Maryport in Cumbria (32857), Vobster Breach in Somerset (Gould 1996, 21). An open-heap site (meiler) has been scheduled at Little Clifton, Allerdale Cumbria (SM 27814). One of the last remaining, working coking plants in England is at the site of Monckton Main Colliery at Royston near Barnsley.

There are many other techniques used in modern coal washing including spirals, cyclones, dense media, froth flotation etc. However, as most such installations were of a period that would have seen all recoverable materials removed after disuse of a colliery and their housing structures demolished, then archaeological evidence is seldom an issue.

4.8 Field archaeology

4.8.1 Archaeological context

Many former coal mining areas have been assiduously landscaped, or have been subject to opencast mining and then redeveloped for a variety of uses. Apart from the obligatory sheave wheel (winding pulley) or tub set into a block of concrete, which mark the site of some former NCB collieries, it is now much easier to find traces of 18th-century collieries than late 20th-century ones. New roads, like the M1 and M62 'joined the dots' in terms of obliterating disused collieries, presumably because they formed islands of derelict,



Figure 4.12 The two lower storeys of the 1791 Serridge Newcomen Engine House were hidden below the surface and their existence entirely unsuspected prior to SGMRG's ten-year programme of excavation and conservation.

© Steve Grudgings

hence cheap, land, and they had spoil heaps which could be incorporated into embankments. Indeed, work on the M1 in West Yorkshire often halted for the NCB to remove any payable coal, but never for archaeological recording of the many early coal mines that were exposed and subsequently erased; such were the policies in the 1950s and 60s. The last twenty years or so have seen a tendency for roads to be built along the course of former railways which served collieries. Nevertheless, using historical mapping and aerial photography, it is possible to recreate many of the complex landscapes of shafts, drifts, tram and railway lines formed in areas of coal and ironstone mining. A good example of this is the Low Moor – Bowling iron works complex of southern Bradford, in West Yorkshire, where large parts of this landscape remained intact until the early 1970s but were then cleared in order to build the M606 link to the M62 and developed into a series of industrial estates. Now only traces remain of a complex series of coal-iron pits and the rail/tramways which fed the ironworks. However, some areas of partly-intact colliery landscape do survive, such as Whitehaven in Cumbria, which has recently been the subject of a

detailed surface survey (Cranstone 2007).

Until the introduction of PPG16 (and later PPG15 for standing buildings), professional archaeologists did remarkably little work on coal mining. This situation has changed greatly for surface features, though development-related archaeology of underground workings (where these are exposed by, for example, opencasting) has remained patchy. As with all development-related archaeology under the PPG system, the majority of reports remain in unpublished 'grey literature'.

Beside their historical studies, mining historians have increasingly developed multi-disciplinary, and equally professional, approaches to their subject. But the archaeological study of coal has a long way to go before it delivers data on the scale for which the historical research has indicated the potential, although following the erasure of the industry, much is now beyond retrieval.

At National Level, English Heritage's Monument Protection Programme turned to mining in the early 1990s and its Step 1 Report (Gould & Cranstone 1993) and Step 3 Assessments (Instone & Cranstone 1994) were the first major archaeological approach to the coal industry; this was subject to the serious constraint of being a search for sites of potential national importance, and much of what was deemed to be of regional importance, or just mundane, was disregarded. Since then the English coal industry has almost disappeared. However, one of the achievements of this work was to assemble all available knowledge on the various industries, and for the archaeology of the coal industry, this was a seminal step. During this process, both the Royal Commission (RCHME) and English Heritage (EH) commissioned photographic surveys of the industry (Thorne 1994; Gould & Ayris 1995). The aerial photographs resulting from these projects are available in the National Record of the Historic Environment (NRHE), together with a large number of individual site survey reports completed by the former RCHME in advance of, and during, the pit closure programme; the NRHE also holds other relevant information.

The English coal industry has not yet been the subject of a national archaeological project and regional studies are few and far between. The exception is Gould's study of the Somerset Coalfield, which focussed on spatial distribution, field archaeology, standing buildings and documentary evidence. The work resulted in a number of publications (Gould 1991; 1994; 1996; 1999; 2005) and established the national importance of an under-reported coalfield, which has a large number of standing buildings and field remains, because much of it was abandoned before British Coal's 'environmental' policies took effect.

Like that for metal mines, the record of coal mines up until the present arises from the usual categories of archaeological activity.

Landscape studies of the type commissioned by National Parks, AONBs, and conservation areas, have been instrumental in increasing knowledge of all the extractive industries. For coal, the Clee Hills (Shropshire) conservation plan is an exemplar of how successful this type of work can be (Barratt et al. 2007). In this project, evidence of the coal industry from several periods was recorded using a varied methodology, resulting in a thorough record of coal in the landscape. Other areas that have benefitted from landscape studies with a coal component on a lesser scale are Nidderdale (LUAU 2000), Hedleythorpe Fell, County Durham (Peters 2007) and Whitehaven in Cumberland (Cranstone 2007). Smaller-scale assessments comprising desk-top surveys, rapid field assessments and walkover surveys have been commissioned in many counties, and have often swelled the numbers of recorded coal sites. A series of much wider, detailed landscape studies for the coalfields have been initiated by Historic England to address aims set out in the National Heritage Protection Plan, beginning with Nottinghamshire. A scoping assessment was carried out by ArcHeritage and the report submitted in May 2014 (Davies et al. 2014) and a full assessment and management plan are currently being developed.

Aerial survey has proved a useful tool in the recording of mainly early coal mining sites, though usually as part of research with broader goals. Nevertheless, coal was covered by the NMP projects covering the Forest of Dean (Small & Stoertz 2006, 97-100), Durham (Radford and Pallant 2008) and elsewhere. Although the data arising from these surveys is seldom assimilated into a useful conclusion specific to industrial research, this is one of the few landscape techniques available that can reflect all surviving aspects of the landscape, and in the case of coal is able to demonstrate early surface evidence, the erasure of the 20th century industry and the dramatic legacy of more recent opencasts. Aerial surveys with outcomes specific to coal have been completed by Cox (2000) and Gould & Ayris (1995).

Watching briefs and pre-construction assessments are usually a precursor to the destruction of a site and the main contribution to this topic from the professional archaeological units. Such studies usually have highly focussed briefs dictated by the developer paying the bill. They are often limited to photographic and descriptive material. Excavations have been commissioned, though they are rarely conducted in response to research questions, but rather to the impending destruction of a site, and frequently are aimed at non-coal related aspects. Exceptions are

Coleorton (Leicestershire), Sharlston (Wakefield), Deepcar (Sheffield). At Broseley in Shropshire, a sequence of desk-based assessment (Page-Smith 2010), followed by earthwork survey (Page-Smith 2011a) and trial trenching enabled the recording of a number of features including capped shafts and some buried brick foundations (Page-Smith 2011b). Many such developer-funded reports are produced as 'commercial in confidence' and the results are often slow to reach the research community if ever.

Research excavations have been carried out mainly by independent researchers, and confined to early coal mines, engine houses and other surface installations. Ironically, the amateur community or independent sector is stealing the march with research excavations aimed at coal industry sites, with active groups having success in Leicester (Neaverson 2000) and Bristol (Cornwell 1991, 12-18; Hardwick & Kemp 2009, 29-42; Grudgings 2009, 43-56; 2015).

Building surveys to date have been mostly photographic. Surveys by RCHME and others were produced as a response to the pending loss of the resource, prior to the closure of large parts of the industry in the 1990s (RCHME 1993; 1994a-f). Smaller recording works have taken place for a variety of

reasons including at Nailsea (Morris 1996), North Somerset (Gould 1996), Whitehaven (Wild 2000) and elsewhere.

HER enhancement exercises have literally put coal on the map in some counties, where data transcribed from large-scale 1st and 2nd edition OS maps have been an important source of material for HER records. Most counties have now undergone this process, and those with coalfields have been able to use this information as a basis for GIS records. Historical reports, written mainly by amateur researchers, from which information on the material remains may be obtained, have been transcribed into records in some HERs. However, ground truthing seldom occurs. From the late 19th century, the coal industry was also well served by photographers and this is one of the best sources of information about the appearance of long-demolished collieries.

Underground archaeology (see Section 11) for coal mining is extremely rare because abandoned sites are off limits to investigators, although occasionally sections of underground workings may be exposed briefly by opencasts, where recording is sometimes possible (see Hartley 1994). However, the majority of archaeological work has had to focus on surface evidence.



Figure 4.13 Pithead structures excavated at Pewfall Colliery, St Helens. © OAN

4.8.2 Archaeological recording

The main evidence for the use of coal in the Roman period in England comes from coal fragments unearthed in Roman archaeological contexts such as villas and military sites (see Section 2.9). Over 200 examples are known in Britain (Dearne & Branigan 1996). Tentative evidence has also been presented for Roman period coal extraction at Wigan, based mainly on the claims of a 19th-century geologist, Edward Hull, who recorded ancient workings he was convinced were of Roman date (Hull 1861). This has not been corroborated, despite the best efforts of the archaeologists working there, and no other Roman period coal mine has been identified in England; although in several areas, unverified claims of Roman coal pits are made, such as Haydon in Northumberland. However, it is likely that all mining fields had Roman activity, though the evidence has so far proved very elusive (see Section 2.9.1).

Although the date may be uncertain, the earliest field evidence for coal extraction comes in the form of earthwork pits and undulations which are the surface remains of backfilled shallow shafts and bell pits (see above). Establishing precise chronologies for these features from earthworks is not possible, but where underground sections have been dated archaeologically they have proven to be at least 15th century (Hartley 1994). The archaeological record has been derived mainly from field recording, such as at the Clee Hills of Shropshire where it is estimated that evidence of over 2000 pits survive (Fig 4.5). The surface evidence in this area was the subject of an earthwork survey by the RCHME in 1983 at 1:2500 and 1:1000 scale, but more recently many have been plotted from aerial

photographs as part of a major re-assessment of the area (Barratt et al. 2007).

Two important community archaeology projects have focussed on the surface evidence of early coal workings; at Middleton Park, south of Leeds and within the Forest of Dean in Gloucestershire.

At Middleton Park, detailed earthwork surveys combined with historical research have provided an important record of the surface remains from coal pits, which facilitated some interpretation. A model was proposed whereby if the cover was less than about 20m above the coal seam one might expect to find groups of tightly spaced shaft mounds. These, it was felt, may be bell pits. As the depth of cover increased, the shafts were found to become more widely spaced and were interpreted as having served pillar and stall workings (Roe 2008). This conclusion of course, may reflect site-specific geological conditions, but if tested elsewhere, it would prove to be a useful technique.

The technique was tested to good effect in the Forest of Dean, where a field investigation was augmented by a number of remote sensing techniques, including resistivity and LiDAR. The latter demonstrated particularly well the marked spatial variation of the pits within a single large area at Bromley Hill (Youles et al. 2008).

Other mining landscapes of this type have survived, especially on unimproved moorland, with known examples at Goyts Moss (Barnatt & Leach 1997, 56-80), North Yorks Moors (Gill 2010a, 19-31) and Tan Hill (Tyson *forthcoming*) but other mining archaeological deposits remain undisturbed on derelict land or in belts of woodland, where they could be identified by using



Figure 4.14 Chatterley Whitfield Colliery in Staffordshire. The most extensive set of surviving colliery surface remains in England. The site is designated with scheduled monument (SM) status but faces an uncertain future. © Phil Newman

LiDAR or through fieldwork.

The knowledge of the below-ground features of these types of workings is less detailed and based mostly on precious few glimpses of such sites when briefly exposed, and ultimately destroyed, by modern opencast workings. This occurred recently at Deepcar near Sheffield in 2008, although (inadequate) recording took place (*inf* S Yorks HER), and Sharlston near Wakefield in 2009 (Fig 4.6); there, a watching brief maintained during coal clearance, and clearance in the seams (between 10 and 20m), identified the extensive and well-preserved remains of pillar and stall workings, drainage adits, shafts, and a variety of timber props, the arrangement of which could be seen in the floor of the workings. Dating material was retrieved and although not yet fully analysed, suggested these were 19th century workings (A Plummer *pers comm*). A full report on this work is awaited.

So far, the best recorded of these sites is Coleorton in Leicester, where artefacts, discarded garments and remains of timberwork combined to provide dates for the workings in the 15th and 16th centuries (Hartley 1994). One rare occasion where underground survey occurred was at Barber's Drift, Ringinglow near Ield; drift workings were recorded there by a caving group, though the published version is very brief (Mathews & Crocker 1987).

Rescue and research excavations have been carried out at pithead sites, though often with limited resources. At Califat in Leicestershire, foundations of two engine houses were uncovered by members of Leicester Industrial History Society. One has been excavated and published (Neaverson 2000), while excavation of the other is ongoing. Work is also in progress at an engine house and other surface features near Bristol at Coalpit Heath by the South Gloucestershire Mines Research Group. Elsewhere, within this coalfield several excavations have been undertaken by the Bristol Industrial Archaeology Society (Cornwell 1991; Lambert-Gorwyn *nd*; Hardwick & Kemp 2009). At Sharlston near Wakefield, an open-area excavation exposed two shafts enclosed by a pit bank, the stone bed for a pumping engine (?Newcomen-type), an associated boiler house, and evidence to suggest the presence of a horse-driven winding engine (A Plummer *pers comm*).

4.8.3 Archaeology and 20th-century coal mines

An exemplary paper, which outlines the recording of a disused but intact colliery, examined the site of Taff Merthyr Colliery in Wales. A detailed photographic and pictorial record of the machinery was completed before demolition of the site in 1993 (Malaws 1997). No such work on this scale has been published in England, and most of the collieries that were closed

in the last decades received little archaeological recording, although photographic records undertaken by RCHME and EH (above), were published as grey reports (RCHME 1994a-f). Working in Somerset, Gould was able to record much 20th century material and various small-scale recording and mitigation surveys have taken place elsewhere. However, it is a sad truth, that much of England's 20th century coal industry has been obliterated without adequate (or any) record. Infrastructure, settlement and housing are in many cases the only remaining signpost to this particular aspect of the recent past.

Since work on this assessment commenced in 2009, collieries at Maltby, Daw Mill, Hatfield, Kellingley and Thorseby, plus the smaller Hay Royds, have all closed. Also, the decision has been made, by Leicester County Council in 2015 to close the Snibston Discovery Museum, and discussions are (2015) in progress aimed at de-listing the grade 2 headgear at Clipstone Colliery (Nottinghamshire, Fig 4.3), to be followed by demolition. Meanwhile, at Chatterley Whitfield (Staffordshire) (Fig 4.14), continuing delays over a decision on its future are contributing to the site not having a future. It is essential that these and others, which will inevitably face closure, should be professionally and thoroughly recorded as the deep mined English coal industry ceases to exist.

4.9 Oil shale mining and production from oil-bearing coal deposits

Peter Cloughton

4.9.1 Introduction and historical context

The production of oil from wells in England is excluded from the remit of this research framework, but the mining and quarrying of shale and some coal, with a view to extracting oil products, has had an impact on the historic environment across a number of English counties. Oil shale workings are to be found in Dorset, Norfolk and West Somerset, and oil-bearing coal deposits were worked in parts of Shropshire, North Staffordshire and Yorkshire.

Although the modern industry, extracting oil from shale deposits, was first developed in France in the 1830s, and later in Scotland in the 1860s, the shale itself was quarried on the Dorset coast (as 'Kimmeridge Coal') and burned as a domestic fuel from the Medieval Period until the 1930s (Kerr 1999, 5; Gallois 2012, 1). The principal period of development in the mining and processing of English oil shale deposits in Norfolk began in 1916, in the latter part of the First World War against a background of fuel oil shortages, but was short-lived as the removal of the high sulphur content in the oil proved insurmountable at the time. Despite this, ill-



Figure 4.15 The surviving retort at Kilve, West Somerset.
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advised attempts to recover oil from shales at Kilve in West Somerset continued through to 1924 with the establishment of the Shaline Company (Gallois 2012). Shale deposits had however been worked for oil, and oil based chemicals, in Dorset at Kimmeridge Bay and inland at Portisham, in the latter part of the 19th century but again the sulphur content was a barrier to large scale working (West 2014).

The extraction of oil and oil based products from coal deposits dates back to at least the 17th century in Shropshire (Luter 2005, 40) but the large scale working of cannel coal for oil dates from the 1850s in Scotland, where it was the basis for Young's patent paraffin oil production and predated the large scale working of oil shale deposits (Kerr 1999, 1-7). Cannel coal was subsequently distilled to produce oil in North Wales (Flintshire) and the North Staffordshire and parts of the Yorkshire coalfields, up until the last decade of the 19th century (Giffard 1938).

4.9.2 Geology

The principal oil bearing shale deposits in England are in the Jurassic Kimmeridge Clay formation, underlying much of Southeast England, Northwest Norfolk, East Lincolnshire and parts of East Yorkshire, and

outcropping along its western boundary on the Dorset coast at Kimmeridge Bay northwards, with its largest surface exposure in Northwest Norfolk (Gallois 2012, 64-65). Oil bearing shales are also found in the Jurassic Lias group on the north coast of West Somerset between Watchet and Hinckley Point (Gallois 2012, 69), and in some Carboniferous Upper Coal Measures, where it is linked to cannel coal deposits accompanying the Black Band ironstones (Giffard 1938, 80). True cannel coal is rare in England but thin lenses of 'bastard' cannel (yielding from 12-60 gallons of oil per ton in the Pitts Hill District of North Staffordshire) occur in the Upper and Middle Coal Measures (Giffard 1938, 81-84). Natural bitumen seepages in Shropshire are also linked to deposits in the Coal Measures (Brown nd., citing Redwood et al. 1906, 32).

4.9.3 Technological context

The extraction techniques for shale and cannel coal mining differed little from that used in other stratified minerals. In fact, the working of cannel and associated shale deposits for oil production was a by-product of coal and iron mining. The technological specialities are in the processing of both oil shale and cannel coal. Distillation in retorts at a 'low red heat' was required to extract the oil (Giffard 1938, 87-88; Kerr 1999, 37-48). The form of the retorts would have developed over time. An early example for recovering tar is illustrated in Luter's paper (2005, 43) and Gallios (2012, 69, Fig 6) illustrates the layout of the Setchey, Norfolk, plant of c.1920. Large numbers of retorts were in use on oil works in the coalfields and the oil shale producing areas; in North Staffordshire, in 1865, there were eight works with a total of 154 retorts (Giffard 1938, 90). Overall some eighteen oil works are listed for England by the Museum of the Scottish Shale Oil Industry, excluding those in Norfolk and West Somerset.

4.9.4 Archaeology

Assessment and recording of the archaeological evidence for the extraction of oil shale and oil-bearing coal deposits, and their subsequent processing, is fragmentary. The extraction and processing sites at Setchey, Norfolk, were the subject of an archaeological assessment (Penn 2005). Stanier included oil shale working in his publication on Dorset's Industrial Heritage (1989) and features related to oil shale extraction are regularly exposed in the cliffs to the east of Kimmeridge Bay (West 2014). The surviving retort at Kilve, West Somerset (Fig 4.15), is a listed building (Historic England 1057429), and the Tar Tunnel at Coalport in Shropshire, the site of natural bitumen extraction, is conserved

with public access. There is, however, little evidence of detailed archaeological investigation, and the extraction and processing of both oil shale and oil-bearing coal deposits are significantly under-represented in the Historic Environment Record.

Notes and Internet sources

1. In 1926, the Mining Industry Act (16 & 17 Geo. V, C.28) gave colliery owners statutory facilities for making amalgamations within the industry.
2. In 1930, the Coal Mines Act (20 & 21 Geo. V, C.28) provided for the establishment of central and district selling schemes to regulate the production and supply of coal; it also set up the Coal Mines Re-organisation Commission.
3. In 1938, the Coal Act (1 & 2 Geo. VI, C.52) set up a Coal Commission to acquire the fee simple in all coal and mines of coal.
4. Following the Coal Industry Nationalisation Act, 1946 (9 & 10 Geo VI, C.59). The National Coal board was set up on July 15th 1946, and to this body were transferred the functions and property of the Coal Commission and the statutory selling schemes, together with the properties and rights in the assets owned by colliery concerns and used for carrying on the industry.
5. www.bgs.ac.uk/downloads/start.cfm?id=829
6. www.bgs.ac.uk/downloads/start.cfm?id=298
7. www.dmm.org.uk/mindex.htm
8. <http://cms.nottinghamshire.gov.uk/historiclandscape.pdf>
9. www.nottsheritagegateway.org.uk/
10. Monopolies and Mergers Commission report on the British Coal Corporation – Presented to Parliament by the Secretary of State for Trade and Industry by Command of Her Majesty January 1989.
11. www.bgs.ac.uk/downloads/start.cfm?id=2555
12. <http://dovermuseum.co.uk/Exhibitions/Coal-Mining-in-Kent/Coal-Mining-in-Kent.aspx>
13. The Cloughton brickworks is re-opening, and the ropeway has been refurbished (March 2014)

5 Iron and Ironstone

Peter Cloughton

Additional material contributed by Mick Atkinson, Ivor Brown, Brian Cubborn, Paul Sowan, Mike Gill and Mike Shaw

5.1 Introduction

The archaeological investigation of iron working in England, as in the rest of Britain, is dominated by the smelting processes, with little attention being paid to the extraction of the ores that were smelted. For the post-medieval period onwards, the increased availability of documentary evidence has meant that many mining historians have addressed the mining of iron ores. However, the coverage is patchy, with a greater focus on the ironstone of the Coal Measures, haematite deposits of Northwest England and other low phosphoric ores worked in Southwest England in the late 19th century. The working of the Mesozoic iron ores along the Jurassic belt from the Midland counties northwards to Cleveland has, with exception of the latter, largely been ignored. As a result, the history and archaeology of medieval and earlier periods abounds with questions regarding the sources of the iron smelted in the many hundreds of bloomery (direct smelting process) sites across England.

The use of iron, and the extraction and smelting of its ores in what is now England, has its origins in the 8th century BC, within the far Southwest, where the Great Perran Iron Lode has been identified as a potential early source of iron ores, through trace element analysis (Ehrenreich 1985, 97-99). By the medieval period, all parts of the country could produce sufficient iron ore to supply a small bloomery hearth. Most of the extraction sites may have been small, sometimes no more than the ephemeral digging of bog iron deposits, and consequently unlikely to attract notice in the wider historical environment. However, there were sources of ore which attracted increased attention from the late Iron Age and Roman periods onwards, and those are highlighted in the discussion below.

There is no overall historical account of iron mining in England, nor have any of its regions been covered comprehensively except perhaps Cleveland, Furness, and the Brendon Hills in West Somerset, and in all those areas the focus has been on modern mining (post 1750). Mining is touched upon in histories of the iron industry from Schubert (1957) onwards, but the focus is normally

on the processing of the ores, not their extraction. A few writers have, however, given some attention to the extraction of ores - see, for example, the work of Cleere and Crossley (1995) and Hodgkinson (2008) in relation to the iron industry of the Weald - and English Heritage's Monument Protection Programme (MPP) included systematic coverage of iron mining (Instone 1995; Cranstone 2001 and 2002). Some individual mines have been covered by historical monographs; one of the earliest being Harris's work on Hodbarrow Mine in Cumberland, through to the recent work by Brooks on the Great Rock Mine in Devon (Harris 1970; Brooks 2004). Taken together these, along with articles published in mining history interest journals, provide good coverage for some regions. There are gazetteers of mine sites and some accounts of the surviving physical features on the mines, which might aid the archaeologist, but most accounts of iron mining, whilst providing the background to the history of individual sites, provide little to assist in their interpretation (e.g. Brown 1975).

5.2 Geology

In Britain, a wide range of iron ores are available, the majority of which had been worked by the medieval period and were known to the 19th-century iron masters (Table 1). Those ores were, of course, not a homogenous product; they varied considerably in their iron content and their chemical composition, with 'impurities', some of which might, or might not, be beneficial, depending on the way they were processed (Cloughton 2005).

As already noted, Iron Age to medieval iron mining used a wide range of ore sources, some of them tiny by later standards. Of the major iron-making areas, the Weald used clay ironstones, and the Forest of Dean limonite. Smaller deposits of Lower Cretaceous clay ironstones, as worked in the Weald, were also worked on other sites across the south of England. For example, in Norfolk, between Weybourne and West Runton, there are extensive iron pits and smelting sites (Fullilove & Dennis 2006), and the cluster of bloomery smelting

Table 1: Iron ores used commercially in Britain during the 19th /20th centuries (based on Atkinson & Baber 1987, Table 5).

Ore type	Chemical name	Location	% metal	As mined
Magnetite	Ferrous or Iron (ii) oxide Fe_3O_4	SW England	72.4	65
Red haematite	Ferric or Iron (iii) oxide Fe_2O_3	West Cumberland Furness Cornwall	70	55-60
Specular & micaceous haematite	Crystallised ferric oxide	Devon	70	55
Brown haematite or limonite	Hydrated ferric oxide $Fe_2O_3 \cdot xH_2O$	SW England Wales Forest of Dean Jurassic Belt*	60	30-45
Spathose ore	Crystallised ferric carbonate $FeCO_3$	Weardale Somerset	48	45
Clay ironstone	Argillaceous ferrous carbonate	Coal Measures Cleveland	20-37	20-32
Blackband	Argillaceous ferrous carbonate with coaly matter	Coal measures - mainly Scotland	17-30	17-30

* Resulting from the alteration of carbonates through weathering - 30% or less metal content.

sites in the Chilterns. The latter has no known iron ore deposits in the immediate vicinity, and the smelters may have sourced their ore from Cretaceous deposits in the Westbury area (discussion at the specialist workshop, Caphouse, February 2011). The Coal Measures clay ironstones were also widely used and, with the development of coke smelting and steam-powered furnace-blowing in the 18th century, extraction centred strongly onto coalfields such as the Black Country, Derbyshire, and South and West Yorkshire.

Clay ironstones, the principal source for the industry prior to 1850, were relatively low in iron content but were found in conjunction with coking coal and limestone. Although their phosphorus content was transferred to the slag in bloomery iron-making, in the blast furnace it passed into the pig iron, and thence into the wrought iron into which most pig was converted. Phosphoric pig was not a problem for most foundry purposes (and could be actively preferred). However, phosphoric ('cold-short') wrought iron was hard and brittle; it was suitable for nail-making, but not for many high-quality purposes, nor for steelmaking. The oxide ores, with the notable exception of the ores from the Jurassic belt, were generally low in phosphorus. Haematite from Furness and West Cumberland mines provided the main British source for 'tough' (non-phosphoric) iron and had been exploited since at least the Middle Ages. The iron masters recognised its value, shipping it to the coalfields as a rich supplement to the local ironstone, improving the quality of the iron product. Development of the Bessemer

process stimulated the search for similar ores. This led to renewed interest in the southwest of England, particularly when the manganese content of ores was recognised as a valuable de-oxidising agent, but interest was not matched by production. Between 1863 and 1889 a total of 30 companies were registered to work iron ores in the Southwest, the bulk of them (26) in the mid-1870s (TNA: PRO, BT286)¹. Of these only about six produced significant amounts of ore (Atkinson, 1981; Burt et al. 1984 and 1987). The haematite deposits in the Brixham area of South Devon produced 300,000 tons in the period 1858-1914 and, in addition, sustained a local paint industry (Ussher 1933, 146-48).

5.3 Historical and archaeological context

5.3.1 Medieval

Sources of information on iron mining prior to the 12th century are, on the whole, sparse; however, although reference to specific mines is rare prior to the 13th century, iron mines are identified at Lyminge in Kent, in AD 689 (Sawyer 1968, 73), and at Rhuddlan in Northeast Wales, then under English control, in 1086 (Domesday, Cheshire [Morris 1978] f. 269). In the Forest of Dean, the Weald of Kent and Sussex, Northamptonshire and southern Lincolnshire, and parts of West Somerset and East Devon, there is evidence for substantial and continued production from the Roman period onwards (Claughton 2010a, 59).

By the late medieval period, the demand from agriculture, building and the material of warfare gave iron production considerable impetus. A widespread industry, already well-established at the Conquest, was developed to supply local and regional demand. Areas specialising in the mining and smelting of iron ores can be identified. These drew on varied ore resources, each requiring different mining techniques.

Historians of the medieval iron industry have focussed attention on certain localities with substantial and sustained production, for example the Sussex Weald, Southwest Yorkshire and the Forest of Dean. However, iron was probably the most common mineral and, in most areas of England, sufficient could be mined to supply a small bloomery. For example, six settlements scattered across the western and southern parts of Somerset are recorded in Domesday as paying, or having paid, dues in iron blooms. The bloom was the product of one firing of the bloomery furnace, hammered to extrude the slag and resulting in a more or less homogenous mass of malleable iron (the direct process). Other payments in iron, or reference to iron working, can be found in at least four other counties (Domesday; Somerset [Morris 1980] 1,4, 3, 1, 17,3, 19,4; 27; 65, 21,75-76; Index of Subjects, 98). It is also becoming evident from archaeological work that there were far more centres of specialisation than had previously been supposed. In Southwest England, recent work has strengthened the view that Exmoor and its borders hosted a thriving iron industry throughout the medieval period (Juleff 1997; Juleff *pers comm*). Similarly, it has been demonstrated that mining and smelting of iron was carried out on the Blackdown Hills of East Devon from the Roman period until at least the mid-15th century (Griffith & Weddell 1996).

A significant proportion of demand for iron was local, for agricultural and building sundries, which makes production difficult to quantify. Schubert has concluded that conflict during the reign of the early Norman kings reduced the agricultural demand for iron. Production recovered in the early 12th century as mines and forges were either acquired, or established, by monastic orders, principally the Cistercians. In the Chartulary Book of Furness Abbey, there is reference to a mine in the Orgrave area near Dalton, now in Cumbria, from 1235 onwards (Fell 1908; Beck 1844). Purchasing of iron by the Crown for military use, either in weapons or in castle building, is well documented, with the Forest of Dean as the largest supplier (Schubert 1957, 81-87 and 94-98). Production of iron in England is estimated to have been around 1,000 tons in 1300 (Miller & Hatcher 1995, 62, citing Pollard & Crossley 1968, 44). This was not enough to satisfy demand fully, and large amounts of iron were imported from Spain and the near continent.

The availability of imported iron may have contributed to a decline in home production after 1300, although it is possible that a shortage of wood had a greater impact. Whatever the causes, the evidence suggests a general fall in iron making capacity before the Black Death (c. 1348-50). One exception appears to have been the Weald, where the proximity of London may have stimulated production. Here the introduction of water power for bloom processing (hammering) suggests a requirement for increased capacity. Renewed demand for iron in the 15th century was again accompanied by the application of water power to smelting and processing, allowing for increased production with the limited labour available. By the end of the century further increases in production were made possible by the introduction of the blast furnace (indirect process) into Southeast England (Schubert 1957, 111-15 and 145; Miller & Hatcher 1995, 63; Crossley 1981). Unfortunately, there is little evidence regarding capital required for iron mining and iron working. Before the 15th century it was probably low and came from the resources of the individual operator. With the introduction of water power to iron working processes, later evidence from the Weald would suggest that landowners were willing to invest in the fixed capital of the ironworks themselves (Zell 1994, 237-38).²

The techniques of mining varied from area to area, depending on the nature of the iron deposits. In some areas bog iron ores, deposited by iron-rich water as a horizon in the soil, were worked at an early date by simple pitting (Tylecote 1986, 125). Stratified clay ironstone in the coal measures of Southwest Yorkshire, comprising a multiplicity of thinly bedded nodular deposits, was well suited to working by means of bell pits once the outcrop deposits were exhausted. These shallow shafts, widened at their base to work as much ground as the roof stability would allow, are generally associated with coal working (see Section 4.6.2). However, they appear to have been developed in the medieval period when iron was of greater value than coal. Abandoned workings are sometimes found back-filled with unwanted coal from the next shaft (Tylecote 1965; Moorhouse 1981), or a shaft sunk to work ironstone nodules would pass through a coal seam without any attempt to work that seam (Guy & Atkinson 2008, 90). Good examples of bell pit³ workings for iron have been found during modern opencast extraction of coal (see Willies 1997b).

Iron deposits in the limestone occur in two forms: either as metasomatic alteration of the limestone to carbonate ironstone, as found in association with lead veins in Upper Weardale, County Durham, or as replacement and karsitic deposits, where iron oxides have replaced the limestone or filled existing cavities within the rock; the latter is exemplified in the Forest of



Figure 5.1 The interior of a scowle near Clearwell in the Forest of Dean. © Phil Newman

Dean and the Furness area of southern Cumbria. From the 12th century, the former were worked at outcrop or in conjunction with lead/silver rake workings (Dunham 1990, 4). In the Forest of Dean, the irregular masses of oxide ores (haematites and limonites) filling all, or part, natural cave systems, were worked at outcrop by a combination of trenching and shallow tunnels, leaving a characteristic series of hollows and exposed caves locally referred to as 'scowles' (Hoyle et al. 2007). Similar workings might be expected in Furness. On the Weald in Southeast England ironstone nodules, found in Lower Cretaceous clays, were worked by pits at outcrop, or by shallow shafts up to 12m deep (Cleere & Crossley 1995, 15-21 and 98-99). In East Devon, the iron nodules, found in the Cretaceous Upper Greensand which caps the Blackdown Hills, have been worked by multiple shallow pits (Griffith & Weddell 1996). Lenticular deposits, as on Exmoor, and fissure deposits (veins) appear to have been exploited at surface as linear openworks, although a positive chronology has yet to be identified (Juleff 1997, 13).

There is archaeological evidence to suggest that some iron mining areas exported their ores for processing elsewhere. A cargo of iron ore was found in a boat, dating from 1240 to between c.1250 and 1280, wrecked at Magor Pill on the Severn estuary. The boat's structure was not suitable for work on the open sea and the probable origin of the ore was at, or near, Llanharry in Glamorgan (Nayling 1998, 105-15), although that source is disputed by Allen (2004a). It does, however, imply a regional trade in iron ores. This is reinforced by archaeological evidence for the movement of Forest of Dean ores across the Severn to the Bristol area (Allen 1996). Even within an area of specialisation, iron ore might be carried some distance before being smelted (Moorhouse 1981). Smelting locations were largely determined by the availability of fuel, wood charcoal, and, from the 15th century, by the availability of water as a power source.

5.3.2 Post-medieval

With the introduction of the blast furnace (the indirect iron smelting process) into England in the late 15th century, there was an acceleration of the movement to exploit more enduring sources of iron ore. Blast furnace smelting, was a bulk production process, eclipsing the bloomery and requiring much larger volumes of ore. Some areas, such as the Weald, continued to maintain a supply of ore, but others rose to prominence, being well placed to sustain the supply, having the woodland resources required to provide the large amounts of charcoal, and water-power for the bellows. Furness, in what was North Lancashire (now part of Cumbria), is a good example. The area had maintained a small but significant iron industry throughout the late medieval period, mainly sponsored by large monastic estates, but the first blast furnaces were not introduced until the early part of the 18th century (Bowden 2000). Exploitation of the rich haematite resources then responded to demand and progressed alongside the expansion of blast furnace production - at least ten charcoal fired furnaces were established in and around Furness with a further five on the West Cumberland ore-field to the north (Riden 1993). A similar expansion in production also occurred in the West Midlands, particularly Shropshire, exploiting the ironstone of the Coal Measures. In the Forest of Dean, a major source of 'tough' iron in the 16th and 17th centuries, the ores above the water-table (and therefore accessible before the development of mechanised pumping) were becoming exhausted, and the blast furnaces relied as much on the re-smelting of older slags as on fresh ore (For a comprehensive study of the development of bar iron production in the post-medieval period see King 2005).

5.3.3 After 1750

After the development of coke-fired blast furnaces during the 18th century, it was the Coal Measure ironstones which rose to prominence as the principal source of ore. By 1850, to satisfy demand for a quality product, the iron industry in Britain had already extended the range of ores it used. As outlined in the Geological Background (above), local ore resources were supplemented by other ores, primarily haematite from mining fields such as Furness on the west coast, shipped into iron works based in those coal fields with suitable coking coal. Yet, after the introduction of coke smelting, some one hundred years earlier, the iron industry remained largely located in those areas which were defined as having favourable ore/fuel resources. The development of railways allowed some extension, for example into upland Northumberland and, more

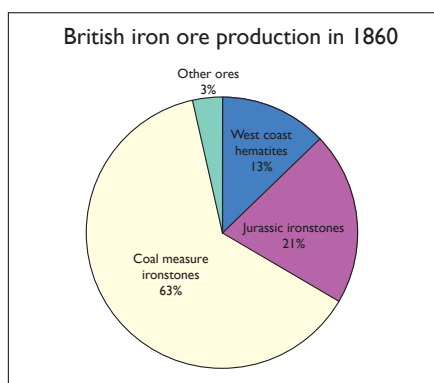


Figure 5.2 Pie chart showing British iron ore production in 1860.

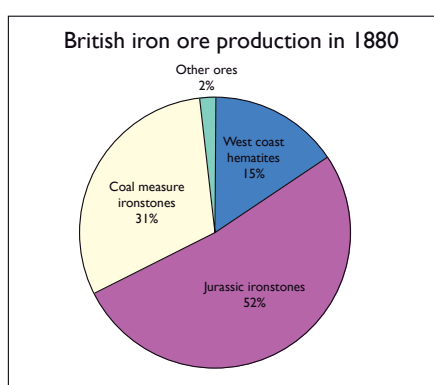


Figure 5.3 Pie chart showing British iron ore production in 1880.

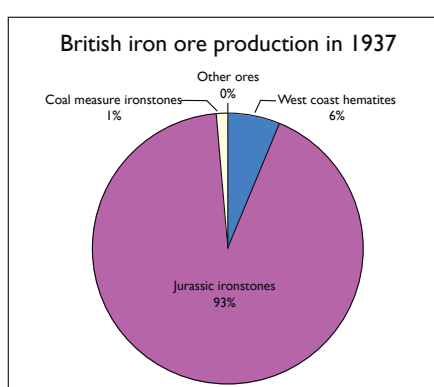


Figure 5.4 Pie chart showing British iron ore production in 1937.

importantly, Teesside. With the development of bulk-production techniques in steel making (such as the Bessemer process), and the response to early failures in technique, came a demand for ores with particular qualities not readily satisfied from local resources.

The Bessemer and Siemens open-hearth processes for making mild steel, developed in the 1850s and 1860s respectively, could only work with low-phosphorus iron. This led to an enormous expansion in demand for non-phosphoric ores, notably from Cumberland, Furness, and the Brendon Hills in Somerset, together with increasing imports of Spanish and other haematites, and to the decline, or even collapse, of some coalfield iron industries. The development of the Gilchrist-Thomas or 'basic Bessemer' resolved this problem by using a lining of dolomite to react with the phosphorus content of the iron and remove it as 'basic slag'. While this stimulated a major expansion of Cleveland iron mining (supplying the Teesside iron industry), and later of the East Midlands Jurassic belt, it did not cause a major revival of coalfield iron mining. Mining technology and economics increasingly favoured the low-grade but massive and easily-worked Mesozoic ores of the Jurassic belt over the smaller Coal Measures deposits, which were less capable of being mechanised and, increasingly, worked-out. These trends continued in the 20th century, with mechanised open-casting promoting a *floruit* of the East Midlands ore-fields, while other ore-fields declined and the remaining blast furnaces relied increasingly on imported ores.

5.4 Technology and techniques

Certain working techniques were, in some cases, unique to the iron ores deposits. In the large irregular haematite deposits of Furness, a technique known as 'top slicing' was used to remove ore from the upper parts first. The ground above the deposit was then allowed to collapse as the supporting pillars of ore were removed and extraction of ore at the next level started. Ore continued to be removed in 'slices' to the full horizontal extent of the deposit, working downwards in stages until all the ore in the deposit had been removed. Subterranean evidence for 'top slicing' is unlikely to be encountered as the ground above was allowed to collapse, leaving the abandoned workings inaccessible; but its use is often evident at surface, leaving immense depressions where the collapse took place, which subsequently flooded after the abandonment of the mine.

In the Cleveland iron mines there were some working techniques which were not adopted elsewhere in metalliferous mining; for example, the use of hand operated rotary or ratchet drills from the late 19th century onwards. In some mines, such as Eston, they were the only form of drill used after about 1903 (Pepper 1996, 14-15; Chapman 1993).

Whilst not unique to the exploitation of iron ores, the techniques of quarrying the Mesozoic ironstones will leave characteristic surface features where large

amounts of overburden have been stripped away using, with time, increasingly large mechanised excavators, including the large walking draglines also used in the opencast working of coal. The widespread use of narrow and standard gauge railways to facilitate the removal of the Mesozoic ironstone in the Midland counties, which continued into the 1960s (Warrington 2013), is also a characteristic not met with on a similar scale in other metal mining industries.

Some techniques in ore preparation have left evidence at surface, which is unique to iron mining. Unlike non-ferrous mining, iron ores were rarely subjected to large-scale mechanical concentration procedures at the mine. Although the crushing of iron ores was not a common practice, it was carried out at some mines working Mesozoic ores; for example, at the Oxfordshire Ironstone workings from around 1920 onwards (Tonks 1988-92, II, 138 *et seq.*). However, most carbonate (and some oxide) ores were roasted, either at the mine or at the furnace; this converted the carbonates to oxides, expelled any sulphur content, and also broke up the as-mined lump ore into smaller, more porous pieces suitable for smelting. Roasting might be in open heaps (with or without permanent bases or chimneys) or in calcining kilns of various forms, with evidence for purpose-built kilns from the late medieval period (Hayes 1988, 110); the former should be detectable by geophysical survey, and the latter survive as prominent features at some mine sites, for example in the Cleveland field (e.g. Owen 1998, 65-71). Some hand picking of Coal Measure ironstone was carried out at surface (Ivor Brown, *pers comm*), and in some cases, as in West Somerset, magnetic concentration and briquetting using a continuous firing kiln were attempted (Jones & Hamilton 2010, 474-75).

5.5 Infrastructure

5.5.1 Settlement

In some areas, once iron mining developed on a large scale remote from other centres of industry, it attracted its own associated settlements. This is evident in the Cleveland area which has villages with characteristics more akin to coal mining settlement, erected by speculative builders to satisfy a rapid expansion in the mid-1800s. Early settlement in this and other expanding ore-fields would have used temporary and barrack accommodation, and evidence for either could survive in some areas (Hempstead 1979, 240-42; see also Owen, 1998, 49-56). In Northwest England, it was the shipping points for iron ores which had a major influence on the settlement pattern. The town of Barrow in Furness owes its existence to the decision by the local iron

companies to export from the port from the 1780s onwards, and in the 19th century the town of Millom, the port of Borwick Rills and settlements such as Haverigg and Steel Green expanded in line with production from the Hodbarrow deposits (Brian Cubborn *pers comm*).

In East Leicestershire, the 19th and 20th century industry has had little effect on the appearance of local villages. Some workers at more remote locations were housed in wooden cabins, which have long since vanished. This was the case in Oxfordshire where Italian and Polish workers were housed in this manner during, and immediately after, the Second World War. An exception is Asfordby Hill in Leicestershire, a new village with brick terraces, developed from the late 1880s to house workers at the Holwell Company's adjacent blast furnaces, (plus foundry and machinery repair shops from the early 1900s). It remained a very self-contained community, with its own school and social club. This pattern would be repeated along the Jurassic belt, where settlement focused on the iron smelting sites.

5.5.2 Transport

Prior to the second half of the 19th century and the rapid expansion of a national railway network, the iron industry relied on coastal and river shipping to supply iron ores of long distances, with horse borne/drawn transport providing the only means of supplying inland ironworks. The use of packhorses is documented in Westmorland in the 17th century, supplying high grade haematite to the Brougham ironworks to supplement local ironstone; their use was probably commonplace in most mining areas prior to the 19th century (Spence 1991, 105).

The work of Eric Tonks on the *Ironstone Quarries of the Midlands* and their railways, highlights the role that transport played in the effective working of the iron mines; railways were used in most iron-ore fields including Cleveland, Northeast Yorkshire (Hayes & Rutter 1974) and West Cumberland (Hewer 1988). Aerial ropeways were used in a local context, as at the Loftus Mine in Cleveland (Chapman 1998, 92). Significant amounts of Cleveland ironstone were shipped by sea from Skinningrove and other harbours on the coast of Northeast Yorkshire, and the majority of the haematite mined in England would have been shipped from Barrow-in-Furness and other ports in Northwest England. However, railways were to provide the essential transport link for the industry.

An essential shift in the location of the iron and steel industry took place within a comparatively short space of time between 1850 and 1900, with the shift in the logic of location taking place really between 1850

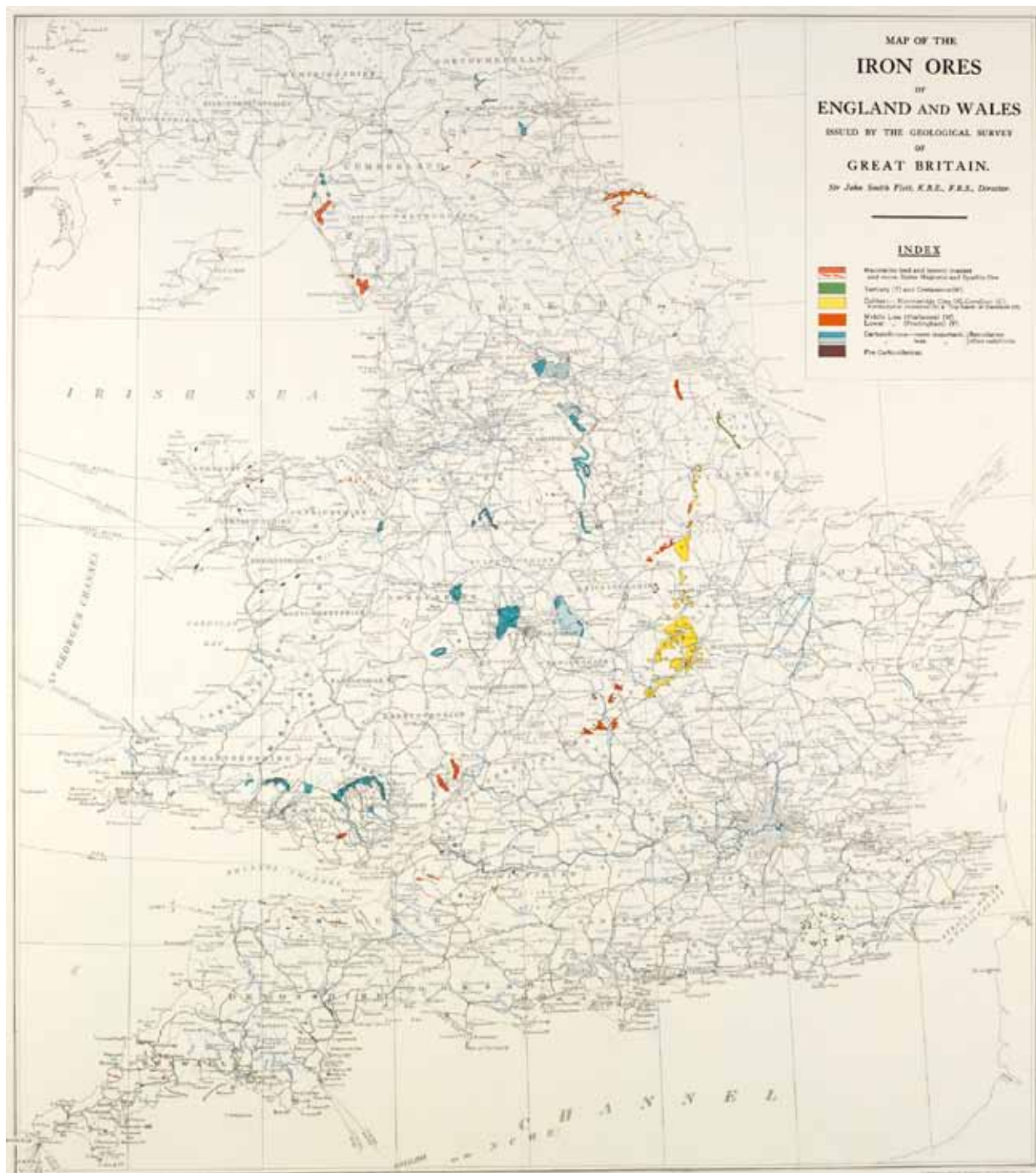


Figure 5.5 Map showing the iron ores of England and Wales.

and 1880. This was caused, in the main, by a dramatic decrease in fuel used per ton of pig, and expansion in the use of British and then foreign haematite ores. The logic had to be very strong to shift an industry which suffered from intense geographic inertia. Transport was a crucial factor for iron and steel masters, who bought their supplies from whoever could supply their required materials to the works at the cheapest rate, including transportation cost.

Because the shift was essentially from coalfield, to orefield, to coast over this short period, and because

the raw material sources had separated, it is essential to emphasise transportation systems associated with the works or regions in considering archaeological remains. It is either a case of local railways, or even canals in the 18th and early 19th centuries, making the exploitation of a particular deposit a viable proposition, or the extension of a regional transportation system to facilitate the development of an entire ironworking area.

Examples of the former would be the Brendon Hills railway (Jones & Hamilton 2010); the Florence tramway

on the southern slopes of Exmoor (Messenger 2002); the Rosedale railway (Hayes & Rutter 1974); the Ravenglass and Eskdale railway; and the opencast Jurassic quarry railways (Tonks 1988-1992). Examples of the latter would be the extension of the Stockton and Darlington (and later the North Eastern Railway) into Cleveland and Weardale and eventually across the Pennines; the Glamorgan, Monmouthshire and Brecon and Abergavenny canals and associated tramways in Southeast Wales; and the Furness Railway in Cumbria. The development of the railway system in the last region was intimately linked to iron mining as demonstrated by Melville and Hobbs (1951). Transport systems deserve a major place in preserving the archaeology of iron ore production.

5.6 The archaeology of iron mining and quarrying

Recorded archaeological investigations of iron mining sites in England, range from overall survey, as with the largely desk based Scowles Project (Hoyle et al. 2007) in the Forest of Dean (Gloucestershire), to the detailed examination of particular mining features with, for example, a gradiometer, or earthwork surveys as at Roman Lode on Exmoor in West Somerset (Dean 2003; Fletcher et al. 1997b); there are also integrated studies of mining and its infrastructure, as on the Brendon Hills, also in West Somerset (Jones & Hamilton 2010). Some investigations have recorded particular features and presented their interpretation in archaeological and historical context as, for example, with the recording of Coal Measure ironstone working including exposures during opencast coal working (Guy & Atkinson 2008, 90; Willies 1997; Moorhouse 1981). In the 1880s shallow shaft workings for Coal Measure ironstone described, possibly accurately, as 'bell pits' quite close to the centre of Leeds were investigated and reported on by an antiquarian (Holmes 1885-86, cited by Sitch 2007, 43). Iron working pits of a similar nature in sandstones of the Millstone Grit series were investigated in the 1870s at Blayshaw in upper Nidderdale, in what is now North Yorkshire, and described as being 'twelve feet deep; the apex being bell shaped and widening at the middle to about seven feet, and at three feet from the bottom to twelve feet', but this and other sites have not been re-examined despite an investigation of potential post-medieval iron smelting in the immediate area (Blacker et al. 1996, 145).

A bibliography of iron mining drawn largely from county Historic Environment Records (HERs), might at first seem quite comprehensive, but few of the works cited in the HERs are records of archaeological

investigation. However, several recent projects have brought iron mining into focus. An example of an integrated approach to iron mining investigations, building on historical research to investigate the extraction processes as part of landscape study, is found in is the RCHME⁴ project *Furness Iron*. Commenced in 1994 and published in 2000. This project included survey work and interpretation on a small number of iron mining sites, some of possible medieval date, and other well documented late 19th century mines in the southwest of what is now Cumbria (Bowden 2000, 12-21). Complementing the work of the RCHME in Cumbria is that of archaeological and mining history groups, some of which has been published; for example the work on the Carter Ground Iron Ore Mine carried out by the Duddon Valley Local History Group (2009, 90-91).

On Exmoor and its borders, West Somerset and parts of North Devon, the investigation of iron mining from the Roman period through to the 19th century has been taken up by academic interests and the local mining history community. The Exmoor Iron Project, looking primarily at the processing of iron ores, has encouraged the study of the extractive processes; the work of Bray for example, on iron production in the Roman period (Bray 2006a). Geomorphological work on the southern slopes of Exmoor has identified the evidence for both Roman and 16th /17th century iron mining; to the east, on the Brendon Hills, the work of the Exmoor Mines Research Group has assisted in the interpretation of the 19th-century activity, which supplied the iron and steel industry in South Wales (Jones 2006). The results of the latter have recently been published as an integrated study of the history and archaeology of mining and its infrastructure, which might be held up as an example of good practice for community led investigation (Jones & Hamilton 2010). Also on Exmoor, at Colton Pits, earthwork survey has revealed the extent of an iron mine, now under plantation, with both 'early' and 18th to 19th-century surface evidence (Riley 2000; Riley & Wilson North 2001, 112-14). The flurry of recent iron-related research on Exmoor has resulted in the publication of a popular field guide (Bray 2010).

In East Devon, on the Blackdown Hills, excavation of one of the many extraction pits for iron nodules in the Cretaceous sandstones provided a Roman period date, although documentary evidence and examination of smelting sites indicate that working extended well into the late medieval period (Griffith & Weddell 1996). Elsewhere in Devon and Cornwall, the focus has been on the history of mining with little investigation of the archaeological features related to ore extraction. Some recent monographs provide useful historical context, including Brooks (2004) *Devon's Last Metal Mine* and



Figure 5.6 Aerial view of opencast Ironstone Works at Crosby Warren, Scunthorpe, 1950. Although fragments of what is visible in this photograph survive, most has been obliterated by later working. © Britain from above EAW028901

(2011) *A History of Iron Mining in Cornwall*; Jones (2011) *The Brendon Hills Iron Mines and West Somerset Railway*. In the Forest of Dean, Gloucestershire, the study of features known as 'scowles' has dominated the archaeological investigation of iron mining; although, as in other iron mining areas, there are historical accounts and the smelting processes have received significant attention (Hoyle et al. 2007).

For those counties where there was working of Coal Measure ironstone, the investigation of mining features is relatively limited. In some cases, the close relationship between the mining of coal and ironstone has masked the evidence for the latter. The work by Willies (1997) and Hedley (1995), taking the opportunity to record and interpret the evidence for early ironstone mining in Derbyshire and County Durham respectively during opencast coal working, has assisted in understanding the techniques used in working iron in the Coal

Measures. It also opens up the potential for further work if adequate archaeological monitoring is in place during opencast coal operations. In the Telford area of Shropshire, the investigation of ironstone working in advance of development work has expanded our knowledge of its working but has not been translated into firm archaeological evidence (Brown 1998). The medieval iron industry in West Yorkshire has been examined by Moorhouse (1981), and he has identified evidence for ironstone extraction. Possible evidence has been highlighted in the course of survey work carried out by the University of Bradford in support of the Judy Woods Project to the southwest of Bradford, but no investigation was undertaken to differentiate it from coal working (Charlton et al. 2006). In respect of some projects looking at iron working in West Yorkshire, Moorhouse has been critical of the lack of appreciation for the overall landscape context for iron

working, where investigation has a tendency to focus on smelting activity without taking in to consideration its infrastructure (Moorhouse 2007, 23). Post-medieval features have also been identified in what is now South Yorkshire, but investigation appears to have been limited to landscape survey with little examination of archaeological features (Fitzgerald 2002; Jones 1995). In some of the coalfields where iron worked alongside coal, there are distinctive features which can mark out iron mining. One example, near Telford in Shropshire, is the characteristic flat-topped spoil dumps clearly identifiable in historic photographs, in some cases, apparently surviving undisturbed under regenerated vegetation (Ivor Brown *pers comm*).

In the southeast of England, the main iron working area was in the Weald of Kent and Sussex where nodular iron deposits were worked in the Lower Cretaceous mudstones (clay). The area has received considerable attention from archaeologists, but again, the main focus has been on the iron smelting processes. Some ore extraction pits, dated to the second half of the 12th century, were examined when exposed during quarrying for material at the Sharpethorne Brickworks and others have been mapped (Swift 1986, 54-55; Cleere & Crossley 1995). In addition, there are frequent references to both the documentary and field evidence for iron ore extraction in the pages of *Wealden Iron*, the Bulletin of the Wealden Iron Research Group.

The working of Mesozoic ironstone from the Midland counties northwards to Cleveland and Northeast Yorkshire was by far the greatest contributor to iron ore production in England from the 1850s to the late 20th century; it is well documented, yet it has largely been ignored by both archaeologists and mining historians. A high proportion of what has been published on ironstone extraction in the Midland counties has come from industrial railway interests, particularly the work of Eric Tonks (1988-1992). Although much of the ironstone workings on the Jurassic belt in the Midland counties have been reclaimed, there are areas of working surviving under woodland, as at Irchester in Northamptonshire. Many of those sites were identified in the English Heritage MPP assessments (Instone 1985, 36-38; Cranstone 2002, 13-14) and some have been subject to archaeological investigation (e.g. Cadman 1997).

Archaeological investigation in advance of late-20th-century ironstone quarrying at Harringworth and Wakerley, in Northamptonshire, identified ironstone extraction pits from the Roman period and earlier, but was not concerned with the quarrying process then underway (Jackson 1981). The 19th /20th century ironstone workings in Lincolnshire have received rather more attention from industrial archaeologists. For

example, the history and surviving features of the Claxby Mine were reported by Squires and Russell (1999) and later reassessed (Squires 2003). These, and the nearby mines at Nettleton, were within the area covered by a RCHME study (Everson et al. 1991); but, whilst making reference to slag finds and other evidence for medieval smelting, no investigation of ironstone extraction was carried out (Everson et al. 1991). To some extent, archaeologists can be assisted in interpreting the field evidence for the late 20th century mines by the recollections of those involved in the industry (e.g. Brown nd; Wells 2005). Some mines are still maintained and might be accessed, with permission, to record the underground features - as at the Dragonby Mine, near Scunthorpe (Brown 2006).

Recent work by the community archaeology group, *Iron-Age Nidderdale*, has focused primarily on investigating late prehistoric and medieval smelting activity at Dacre in the lower part of the dale above Knaresborough, North Yorkshire. They have, however, also made an assessment of the field evidence for potential, largely unrecorded, iron extraction sites from Kirby Overblow, in the Wharfe catchment south of Knaresborough, to the upper parts of Nidderdale (Brophy *forthcoming*). In Redesdale, Northumberland, centred on Rochester and near Ridsdale to the south, are two groups of extensive ironstone workings, exploited from at least the Roman period through to the 19th century. The latter period being covered in a comprehensive study on the history of mineral resource exploitation (Roberts 2000). Those within the Otterburn ranges have been catalogued as part of 'An Archaeological Survey of the Ministry of Defence Training Area' (Charlton & Day 1977, 126-27). Apart from one or two smelting sites, most sites are recorded without comment in the Northumberland HER and, despite their extensive nature, no archaeological investigation has been carried out. Cleveland and the iron mines in Northeast Yorkshire have, by contrast, been studied in some detail by mining historians and industrial archaeologists (see Tuffs 1997 for a selected bibliography). There are numerous reports by the Cleveland Industrial Archaeology Society (CIAS) on the mines and the associated infrastructure such as calcining kilns (Cooke & Owens 1994).⁵

Recent work

In Cumbria, an archaeological assessment was carried out for the Bangarth and Blea Tarn Iron Mines on behalf of the National Trust (Schofield & Vannan 2012). The work included a detailed topographical survey of the mines, identifying a range of features related to their working in the late 19th to early 20th centuries, including elements of the transport system.

The iron smelting site at Churchill's Farm, Hemyock,

in East Devon, excavated in 2008 has been reassessed with, amongst others, the objective of determining ‘What was the source(s) of ore smelted at Hemyock and was this operation part of a larger organised industry?’ (Smart 2014). This will, perhaps, link it in to the wider industry in that part of Devon and the Blackdown Hills. The work is on-going.

Also in Southwest England, recently published work on ochre mining in the Mendip and Bristol area has highlighted the extraction of iron ores alongside the colour pigments, with some significant surviving surface features and the potential for underground archaeological evidence (Clarke et al. 2012, 30-31, 168-72 and 174-77). For the post-medieval iron industry in the Midland counties, work by Peter King has highlighted a number of points, including the dominance of the Coal Measure ironstones and the role fuel supply played in determining where the ores were processed then and earlier, in the medieval period (King 2011).

Notes

1. The National Archives Board of Trade: Companies registered in Truro (BT286).
2. This is in contrast to other parts of England where, at a different stage of industrial development, the aristocracy rather than the local gentry were providing the finance (King 2001, 22).
3. The term ‘bell pit’ should only be used if proven underground. At surface, the evidence for shallow working (i.e. the spoil) might be referred to as a shallow shaft mound (see *also* Section 4, 97).
4. Royal Commission on the Historical Monuments of England. Merged in 2000 with English Heritage - now Historic England since 2015.
5. A list of CIAS publications can be downloaded as a PDF document at www.teesarhaeology.com/new/documents/CIAS_Publications_2008.pdf

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