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Mineral Resource Information in Support of National, Regional and Local Planning

Cumbria and the Lake District:
Resources and Constraints

TECHNICAL REPORT WF/01/02
Mineral Resources Series

Mineral Resource Information for Development Plans: Phase One Cumbria and the Lake District (Cumbria, Lake District National Park and part of Yorkshire Dales National Park) Resources and Constraints

B Young, D E Highley, D G Cameron, D Millward, D J Harrison, P J Henney, S Holloway, G K Lott and G Warrington

Planning Consultant: J F Cowley
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This report accompanies the 1:100 000 scale maps: Cumbria and the Lake District Mineral Resources (North and South) and Sand & Gravel Resources (1:150 000)

Cover Photograph
Aerial View of Shap Beck Quarry, Shap, Cumbria, showing aggregate workings in the Knipe Scar Limestone. Photograph courtesy of Hanson Aggregates North, © Hanson Aggregates North, York Road, Wetherby, West Yorkshire, LS22 7NS.

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SUMMARY

This report is one of a series prepared by the British Geological Survey for various administrative areas in England and Wales for Phase One of the Department of the Environment, Transport and the Region's research project *Mineral Resource Information for Development Plans*.

The report and accompanying maps relate to the area of the Mineral Planning Authorities of Cumbria and the Lake District National Park. The report and maps delineate and describe the mineral resources of current, or potential, economic interest in the area and relate these to national planning designations which may represent constraints on the extraction of minerals. Three major elements of information are presented and described:

- the geological distribution and importance of mineral resources
- the extent of mineral planning permissions and the location of current mineral workings
- the extent of selected planning constraints (national statutory designations)

This wide range of information, much of which is scattered and not always available in a consistent and convenient form, is presented on two digitally-generated summary maps. For reasons of clarity, sand and gravel resources are separated from all other mineral resources. The maps are produced at 1:100 000 scale (1:150 000 for sand and gravel), which is convenient for overall display and allows for a legible topographic base on which to depict the information. In addition, as the data are held digitally using a Geographical Information System (GIS), easy revision, updating and customisation are possible, including presentation of subsets of the data at larger scales.

Basic mineral resource information is essential to support mineral exploration and development activities, for resource management and land-use planning, and to establish baseline data for environmental impact studies and environmental guidelines. It also enables a more sustainable pattern and standard of development to be achieved by valuing mineral resources as national assets.

The purpose of the work is to assist all interested parties involved in the preparation and review of development plans, both in relation to the extraction of minerals and the protection of mineral resources from sterilisation, by providing a knowledge base on the nature and extent of mineral resources and the environmental constraints which may affect their extraction. However, it is anticipated that the maps and report will also provide valuable data for a much wider audience, including the minerals industry, the Planning Inspectorate

Agency, the Environment Agency, the Countryside Agency, other agencies and government bodies, environmental interests and the general public.

The mineral resource information has been produced by the collation and interpretation of data principally held by the British Geological Survey. The methodology for the collection and display of the data is described and a range of sources of information and further contacts is presented. The mineral resources covered are coal, crushed-rock aggregate, comprising limestone, sandstone and igneous and metamorphic rocks, sand and gravel, clay and shale, including fireclay, building stone, slate, peat, hydrocarbons, gypsum and anhydrite, salt, secondary aggregates and metalliferous minerals.

INTRODUCTION

'Resources of some minerals are extensive whilst others are more localised. Environmental and development constraints mean that not all resources can be worked. It is important to identify where extraction will have least effect on landscape, environment and quality of life…'

A Better Quality of Life. A Strategy for Sustainable Development for the United Kingdom. Department of the Environment, Transport and the Regions. May 1999.

This report is one of a series that has been prepared by the British Geological Survey for various areas in England and Wales as part of the Department of the Environment, Transport and the Regions' research project *Mineral Resource Information for Development Plans*.

The report relates to the administrative areas of Cumbria, the Lake District National Park and a small part of the Yorkshire Dales National Park and should be used in conjunction with the two mineral resources maps of the area, which accompany this report. All references to 'Cumbria' or 'the county' made in this report should be taken to also include the area covered by both authorities, although the maps also include a small part of the Yorkshire Dales National Park. The report and its associated maps delineate and describe the mineral resources of current or potential economic interest in Cumbria. These are related to national planning designations which may represent constraints on the extraction of minerals. The purpose of the work is to assist all interested parties involved in the preparation and review of development plans, both in relation to the extraction of minerals and the protection of mineral resources from sterilisation. It provides a knowledge base, in a consistent format, on the nature and extent of mineral resources and the environmental constraints which may affect their extraction. An important objective is to provide baseline data for the long term. The results may also provide a starting point for discussions on specific planning proposals for mineral extraction or on proposals which may sterilise resources.

All the data are held in digital form which can be readily revised on a regular basis. This also provides scope for producing customised maps of selected information, including the display of part of an administrative area in greater detail or a grouping of administrative areas to provide a broader picture. The mineral resource maps are at

1:100 000 which is a convenient scale for overall display and to show the information on a legible topographic base. For reasons of clarity, sand and gravel resources are separated from all other mineral resources and shown separately at 1:150 000 scale. The report and maps represents the situation at 1st January 2000.

Mineral resources are valuable national assets and adequate supplies of minerals are essential for the sustainable development of a modern economy. Society enjoys important benefits from their extraction and, most importantly use, through their contribution to wealth creation, our infrastructure and quality of life of individuals.

Minerals can only be worked where they occur in sufficient quantity and of the desired quality. However, minerals extraction, particularly in the densely populated landmass of Britain, causes conflicts with other desirable aims of society, either by loss or change to valued landscapes, habitats or features of historical and archaeological interest, and/or, due to amenity impact. Ultimately, however, a well restored mineral site may provide new and diverse environmental or development assets.

Basic mineral resource information is essential to support mineral exploration and development activities, and this may lead to an expanding resource base. Data on the properties of resources, as well as their distribution, allows specific resources to be matched with their most appropriate use. An understanding of whether these properties can be modified or enhanced by blending and/or mineral processing allows scope for producing value–added products, as well as facilitating the use of more unconventional deposits, including mineral wastes. All these factors will contribute to the more efficient use of mineral resources. In the wider context of sustainable development, mineral resource information is of increasing importance for resource management and land-use planning. These data also contribute to the baseline information needed for environmental impact studies and environmental guidelines. Moreover, knowledge of the extent and quality of mineral resources, and their rate of extraction, can help value them as national assets. This ensures that the capital they represent is managed properly and rates of depletion monitored.

MINERALS PLANNING

It is the function of the planning system through the development plan and individual decisions to manage the supply of essential minerals at best balance between economic, social and environmental considerations. Achieving that balance requires adequate data on the relevant competing objectives, including the extent and details of mineral resources. As the development of workable resources in environmentally acceptable areas is becoming more difficult, it will become increasingly important in the policy

development process to have comparative and reliable data on the distribution and quality of such resources.

The 'development plan' includes structure plans, which contain strategic planning policies, and local plans, containing detailed policies and proposals, or unitary development plans, which combine both functions. In addition, relevant authorities must produce local plans on minerals and/or waste. Development plans set out the main considerations on which planning applications are determined and form the essential framework of the planning system. The importance of the development plan system in planning decisions is emphasised by Section 54A of the Town and Country Planning Act 1990, which requires that planning applications and appeals be determined in accordance with the development plan, unless material considerations indicate otherwise. The planning system is, therefore, a plan-led system. Development plans are produced through an extensive process of consultation with prospective developers and the general public. Development plan preparation must take account of Government guidance. This is primarily set out in Planning Policy Guidance notes (PPGs), Mineral Planning Guidance notes (MPGs) and Regional Planning Guidance notes (RPGs). These provide advice on a range of general and specific issues.

The Planning and Compensation Act 1991 introduced a mandatory requirement that all Mineral Planning Authorities (MPAs) in England and Wales prepare either a local plan or a unitary development plan which set out policies and proposals against which planning applications and appeals are determined. Mineral local plans are intended to provide a clear guide to mineral operators and the public where mineral extraction is likely in principle to be acceptable and where not. They cover a period of at least 10 years and are reviewed periodically to take account of new information and changing circumstances. MPAs are, therefore, required to undertake regular assessments of the existing resources in their areas and of the reserves for which planning permissions have been granted.

The key elements of a minerals local plan or of the mineral policies of a unitary development plan are:

- to balance through its policies the essential need for minerals against protection of the environment and local amenity
- to make an appropriate provision for the supply of minerals and provide an effective framework within which the minerals industry may make planning applications
- to set policies for the control of mineral working and associated development
- to identify areas of possible future mineral working

- to prevent unnecessary sterilisation of resources by the use of safeguarding policies, including defining mineral consultation areas

It follows from the above that information on the extent, quality and, if possible, quantity of mineral resources is an essential prerequisite for the production of mineral local plans. This includes identifying areas of future mineral working and the longer term objective of the protection of important mineral resources against sterilisation. Policy decisions should be based on the best available information. Such data should be available to all parties to assist them in their contribution to the development plan process, both to protect mineral resources from sterilisation and to provide for sufficient resources to meet the needs of society. This work is intended to assist that process.

Three major elements of information are presented and described:

- the geological distribution and importance of mineral resources
- the extent of mineral planning permissions and the location of current mineral workings
- the extent of selected planning constraints (national statutory designations)

The maps bring together a wide range of information, much of which is scattered and not always available in a consistent and convenient form. The data are held digitally using a Geographical Information System (GIS), which allows for easy revision, updating and customisation, including presentation of subsets of the data at larger scales. It is anticipated that the maps and report will also provide valuable background data for a much wider audience, including the different sectors of the minerals industry, other agencies and authorities (e.g. The Planning Inspectorate Agency, the Environment Agency, the Countryside Agency and English Nature), environmental interests and the general public.

MINERAL RESOURCE CLASSIFICATION

Mineral resources are natural concentrations of minerals, or bodies of rock, that are or may become of potential economic interest as a basis for the extraction of a commodity. They will exhibit physical and/or chemical properties and be present in sufficient quantity to be of intrinsic economic interest. Mineral resources are thus economic as well as physical entities.

The identification and delineation of mineral resources is inevitably somewhat imprecise as it is limited not only by the quantity and quality of data currently available but also involves predicting what might, or might not, become economic to work in the future. The assessment of mineral resources is, therefore, a dynamic process

which must take into account a range of factors. These include geological reinterpretation as additional data become available, as well as the continually evolving demand for minerals, or specific qualities of minerals, due to changing economic, technical and environmental factors. Consequently, areas that are of potential economic interest as sources of minerals may change with time. Criteria used to define resources, for example in terms of mineral to waste ratios, also change with location and time. Thus, a mineral deposit with a high proportion of waste may be viable if located in close proximity to a major market, but uneconomic if located further away. The criteria used to delineate mineral resources are outlined in the relevant commodity section of the report. These criteria vary depending on the quality of the information available.

The maps of Cumbria mainly show the extent of **inferred mineral resources**, that is those mineral resources that can be defined from available geological information. They have neither been evaluated by drilling or other sampling methods, nor had their technical properties characterised, on any systematic basis. Mineral resources defined on the map delineate areas within which potentially workable minerals may occur. These areas are not of uniform potential, nor do they take account of planning constraints which may limit their working. The economic potential of specific sites can only be proved by a detailed evaluation programme. Such an investigation is an essential precursor to submitting a planning application for mineral working. The individual merits of the site must then be judged against other land-use planning issues.

That part of a **mineral resource** which has been fully evaluated and is commercially viable to work is called a **reserve** or **mineral reserve**. The relationship between **measured, indicated** and **inferred resources** and evaluated commercial deposits (**reserves**) is described in more detail in Appendix 3. In the context of land-use planning, however, the term **mineral reserve** should strictly be further limited to those minerals for which a valid planning permission for extraction exists (i.e. **permitted reserves**). Without a valid planning consent, no mineral working can take place and consequently the inherent economic value of the mineral resource cannot be released and resulting wealth created. The ultimate fate of mineral reserves is to be either physically worked out or to be rendered non-viable by changing economic circumstances.

The mineral resource information has been produced by the collation and interpretation of data principally held by the British Geological Survey. The geological lines are taken, with some generalisations, from available BGS 1:50 000 and 1:63 630 scale maps. These published maps are based on 1:10 560 or 1:10 000 scale surveys. In general, the more recent the survey the more detailed it is likely to be.

Where sand and gravel assessment studies have been undertaken by the British Geological Survey, sufficient information may be available to define mineral resources at the **indicated resource level**. The sand and gravel resources of the Brampton area (Jackson, 1979) fall into this category. The linework is based on the 1:25 000 scale mineral assessment maps, where these are available.

MINERAL WORKINGS AND PLANNING PERMISSIONS

The location and name of mineral workings that are currently active or temporarily inactive, together with the main mineral commodities produced, are shown on the map and in Appendix 1.

The extent of all known mineral planning permissions (other than coal) is also shown on the Mineral Resources Maps. They include all permissions granted since 1st July 1948 and all Interim Development Order permissions, whatever their subsequent status in relation to legislation relating to the Planning and Compensation Act 1991 and the Environment Act 1995. Planning permissions cover active mineral workings, former mineral workings and, occasionally, unworked deposits. They represent areas where a commercial decision to work minerals has been taken in the past and where the permitted mineral reserve may have been depleted to a greater or lesser extent. Within the overall site, there may be a number of individual planning permissions at various stages of development and restoration. All planning permissions data were obtained from Cumbria County Council and the Lake District National Park Authority, which are the Mineral Planning Authorities (MPAs) for the area.

The present physical and legal status of individual permissions is not qualified on the maps or in the report. The areas shown may, therefore, include inactive sites, where the permission has expired due to the terms of the permission, i.e. a time limit, and inactive (dormant) sites where the permission is still valid. Sites which have been restored have not been separately identified. However, information is available on the planning and operational status of each planning permission on the database that underpins the maps. A planning permission may extend beyond the mapped resource as it may make provision for operational land, including plant, overburden tips and landscaping, or it may extend to an easily identified or ownership boundary. Information on the precise status and extent of individual planning permissions should be sought from the appropriate Mineral Planning Authority (Appendix 2).

ENVIRONMENTAL DESIGNATIONS

The maps show the extent of selected, nationally-designated planning constraints as defined for the purposes of this study. These

are defined on a common national basis and therefore represent a consistent degree of constraint across the country. No interpretation should be made from the map with regard to the relative importance of the constraints, either in relation to mineral development proposals or in relation to each other. Users should consult policy guidelines issued by the relevant Government department, statutory agency or local authority.

The constraints shown on the map are:

- The Lake District and Yorkshire Dales National Parks
- Areas of Outstanding Natural Beauty (AONB)
- National Nature Reserves (NNR)
- Sites of Special Scientific Interest (SSSI)
- Scheduled Monuments

Mineral development may also be constrained by other factors not shown on the maps including local landscape designations, considerations relating to the protection of other resources, such as groundwater, and local amenity or environmental concerns such as noise, traffic and visual impact. These have been excluded because the constraint is not defined on a national basis or the information is not generally available. The extent or degree of relevance of such constraints can be ascertained from the relevant statutory agency or the appropriate MPA (Appendix 2).

AONBs have been digitised from maps obtained from the Countryside Agency and English Nature provided digital data on SSSIs and NNRs. Information on the location of Scheduled Monuments has been obtained in digital form from English Heritage. The areas shown as NNRs and SSSIs may also be subject to international designations reflecting their wider ecological importance. They may include Ramsar sites (wetlands of international importance as listed in accordance with the Ramsar Convention), or proposed Special Protection Areas (SPAs) and Special Areas of Conservation (SACs) as identified in accordance with EC Directives on wild birds and natural habitats, respectively.

MINERAL RESOURCES

OVERVIEW

The area covers the whole of the Lake District, the adjoining west and south Cumbria iron orefields, the Cumbrian Coalfield, the Vale of Eden and parts of the Northern Pennine Orefield. It is an area of very varied geology in which a wide range of rock types of many different geological ages host a range of sedimentary mineral resources, as well as vein mineralisation and replacement deposits.

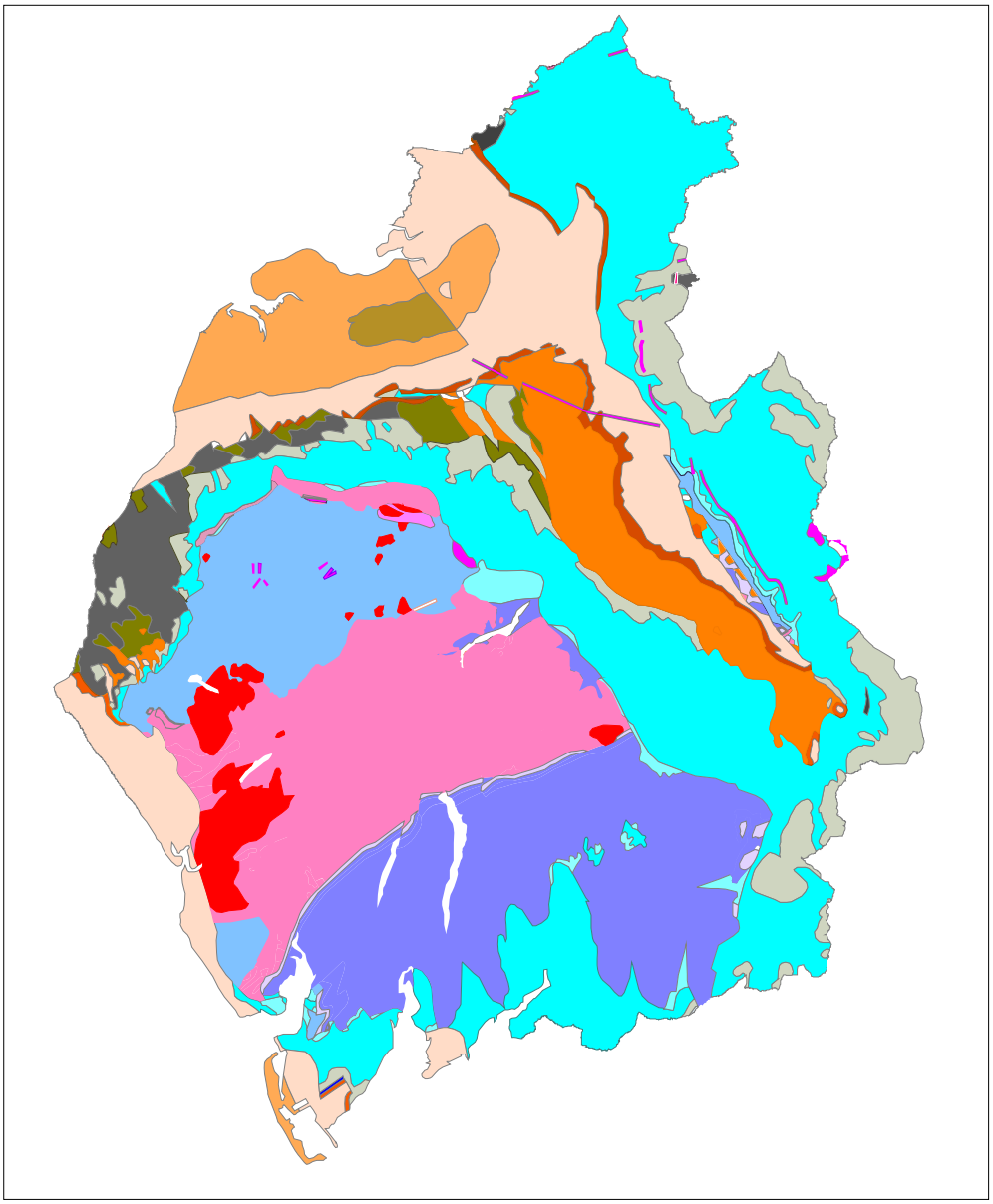


Figure 1. Generalised solid geology of Cumbria based on BGS 1:625 000 sheets north and south, solid.

Figure 1.1 Key for Figure 1. Commodities and resources that are no longer worked are shown in blue.

Mineral working in the Lake District dates back to Prehistoric times. The earliest evidence of organised mineral working dates from the Neolithic Period when fine-grained siliceous siltstone from the Borrowdale Volcanic Group was worked for making stone axes. These are known to have traded across Britain and Europe.

The area also encompasses the mineralised central Lake District and the western parts of the Northern Pennine Orefield. The first reliable records of metal mining in the Lake District date from the 13th, 14th and 15th centuries, but metal mining seems to have been widespread

by the 16th century when, under the influence of Elizabeth I, German miners were recruited to develop the Lake District mines. At this time the area was of European importance as a copper producer. However, in the closing years of the 19th century the exhaustion of the most accessible deposits and a fall in lead and copper prices resulted in a serious decline in the industry. A few base metal mines survived into the 20th century, most notably the Greenside lead mine near Ullswater, which closed in 1960. Small quantities of arsenic, cobalt, manganese, nickel, tungsten and zinc have been produced. The only working for tungsten outside south-west England was the Carrock Fell Mine, which closed in 1981. Further vein-style base metal mining in the area is highly unlikely. However, parts of the area are prospective for stratabound base metal deposits.

Clay ironstone was produced from the Cumbrian Coalfield, but iron ore mining and smelting in the area was dominated by the large high-grade hematite deposits of south and west Cumbria. The late 19th century was the heyday of production following the invention of the Bessemer steelmaking process which allowed steel to be produced from low-phosphorus pig iron. Large-scale mining continued until 1980 when the remaining iron ore mines closed. Small-scale production of hematite continues today at the Florence Mine, near Egremont, for foundry and pigment applications.

Coal occurs within, and continues to be worked from, rocks of both Early (Lower) and Late (Upper) Carboniferous age. By far the greatest concentration of coal seams occurs in the Upper Carboniferous Coal Measures of the West Cumbrian Coalfield. Mining reached a peak in the last half of the 19th and first half of the 20th centuries. It was the presence of abundant iron ore and coal reserves that lead to the development of the iron and steel industries in south and west Cumbria. The last deep mine, the Haig Colliery, which worked up to 6 km offshore, closed in 1984. However, the north-western part of the coalfield is still of interest for opencast coal. Opencast coal sites are also a source of fireclay for brick manufacture.

The area has been important for the production of a wide range of non-metallic minerals. These include graphite, diatomite, salt, barytes, and gypsum and anhydrite. The graphite deposit at Seathwaite in Borrowdale provided the basis for the Keswick pencil industry which continues today using imported raw materials. Diatomite from a post-glacial lake deposit at Kentmere was worked until the late 1970s for insulation purposes. Salt brine pumping was carried out on Walney Island, near Barrow-in-Furness during the early part of the 20th century. Anhydrite for the manufacture of sulphuric acid was mined on a large scale near Whitehaven and in the Vale of Eden until 1975. Gypsum mining continues in the Vale of Eden today for the manufacture of plaster and plasterboard,

together with anhydrite for cement making and specialist applications.

The Lakeland slate industry is still thriving but, as elsewhere in Britain, the main emphasis on mineral production in the area is now the extraction of sand and gravel, and crushed rock for use as aggregate, together with high-purity limestone for a range of industrial applications. The supply of these materials within, or close to, areas of high landscape amenity value is likely to be the major minerals planning issue for the foreseeable future.

COAL

The Coal Measures rocks of the West Cumbrian Coalfield have been the principal source of coal in the county. An isolated outcrop of Coal Measures rocks in the north-east of the county, around Midgeholme, has also yielded important tonnages. Smaller amounts of coal have been, and still are, raised from pre-Coal Measures Carboniferous rocks in the north-east of the county.

The main West Cumbrian Coalfield occupies a comparatively narrow outcrop which extends northwards from Whitehaven, through Workington to Maryport and thence eastwards to Aspatria and Bolton Low Houses. Although Coal Measures rocks crop out east of this, a progressive reduction in the number of the seams and a marked deterioration in the quality, due to oxidation, of those which remain, have rendered this portion of the outcrop unworkable. These easterly Coal Measures have, therefore, been excluded from the Mineral Resources map. Further east, very poorly exposed Coal Measures rocks also occur in the Vale of Eden. No coal of economic value has been recorded in this area and this too is excluded from the map. However, the full extent of both exposed and concealed Coal Measures rocks are shown on an inset map for coalbed methane potential.

Across much of the main coalfield the Coal Measures crop out at surface, though in the extreme south these rocks are locally overlain unconformably by the red-bed succession of the late Carboniferous Whitehaven Sandstone. South of Whitehaven, Carboniferous rocks pass beneath an unconformable cover of Permo-Triassic rocks. Important summaries of the geology of the coalfield are included in Eastwood (1930), Eastwood et al. (1931), Eastwood et al. (1968), Young and Armstrong, (1989), Young and Boland (1992), Boland and Young (1992) and Akhurst et al. (1997).

Within the main coalfield seams of economic interest are confined to the Lower and Middle Coal Measures, the combined thickness of which is about 300 m (Figure 2). The base of the Coal Measures is taken at the base of the Subcrenatum Marine Band, though the lowest workable coal, the Harrington Four Foot seam, typically

occurs several metres above this. Over 30 named seams are known and have been worked to a greater or lesser extent. Seams may locally reach 4.5 m or more in thickness, though smaller thicknesses are more typical. Minor seams, and local splits of the main seams assume importance locally. In places, even the better seams deteriorate in thickness or quality and locally may have been either partially or completely removed by contemporary erosion to form washouts (known locally as 'nips'). Mudstone or 'dirt' partings adversely affect some seams and may locally render them uneconomic. Most seams consist of bituminous coal of high volatile content with strong caking properties, well suited to coking, steam raising, household use and, formerly, gas-making. Jones (1951) provided descriptions of the characteristics of Cumbrian coals. Few recent analytical data have been published, although Taylor (1978) notes a volatile content from 32–39 per cent, calculated on a dry ash-free basis. Pyrite is a common contaminant of some seams.

The West Cumbrian Coalfield has enjoyed a long and distinguished history of coal production with records of mining known from at least the mid-16th century to the present day. It was, however, the latter half of the 19th and early part of the 20th centuries which witnessed the heyday of the industry. Abundant high quality coking and steam coals, together with the large local deposits of hematite iron ore provided the foundation for the heavy industrial economy of west Cumbria. Over the centuries the coalfield has played an important role in the development of the technology and safety of coal mining. Histories of the Cumbrian coal industry include those by Wood (1988) and Calvin (1992).

During its peak years of production almost the entire output of coal was obtained from underground mines. During the final years of deep mining, coal extraction became concentrated in a handful of coastal collieries in which workings extended up to 6 km offshore. Large-scale deep mining came to an end in 1984 with the closure of Haig Colliery, at Whitehaven. An attempt to re-start underground mining commenced during the 1980s at the newly sunk Main Band Colliery, near Whitehaven, but has so far proved unsuccessful.

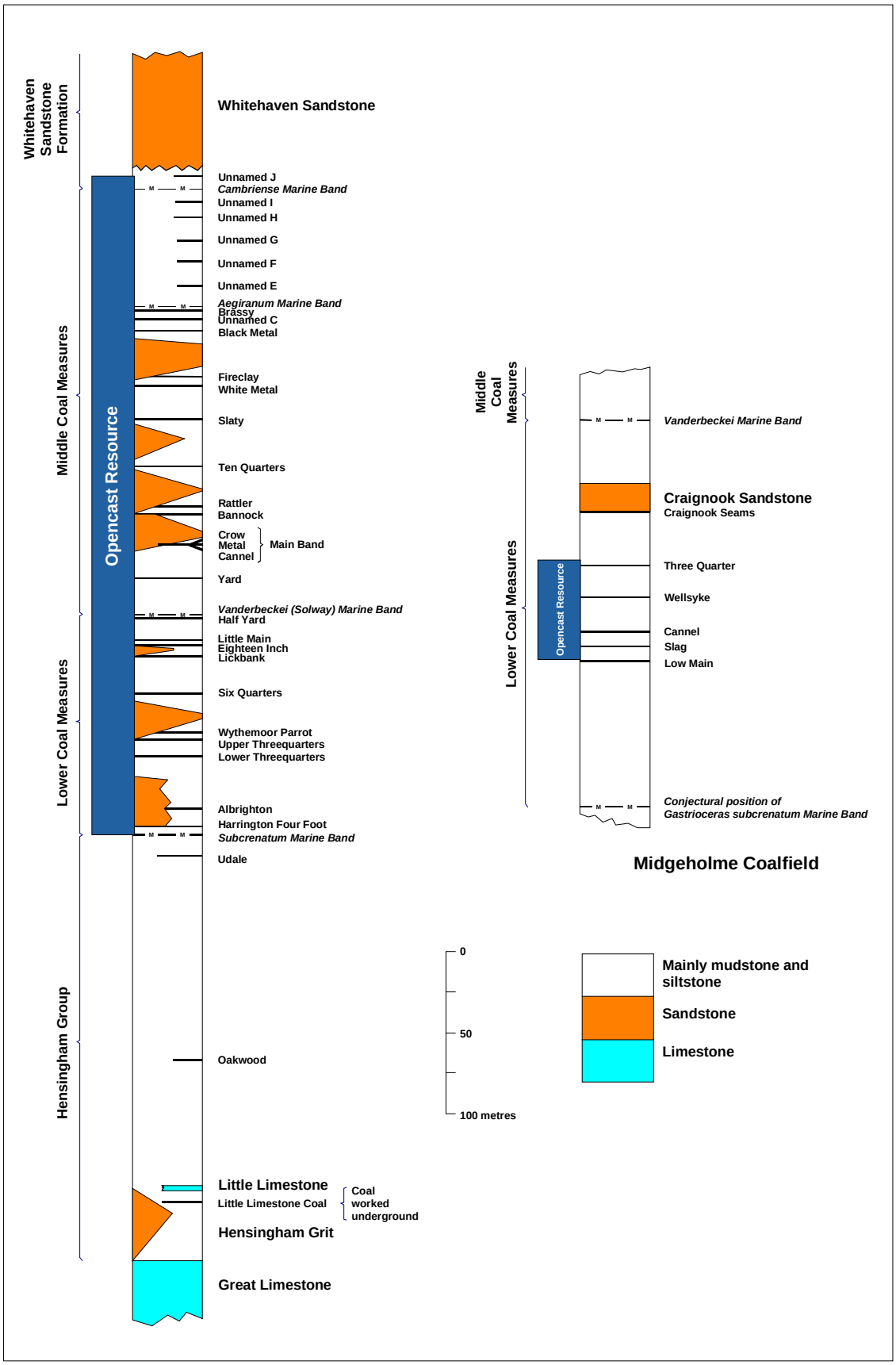


Figure 2. Generalised vertical section of the main coal-bearing strata of Cumbria showing main named coal seams and resource areas.

In the extreme north-east of the county, east of the Pennine Faults the isolated Midgeholme Coalfield lies partly within Cumbria. Coal Measures rocks, with affinities intermediate between the West Cumbrian, and Northumberland and Durham coalfields, here occur as an outlier on the downthrow side of the Stublick Fault. The succession of seams is shown in Figure 2. Several seams have been worked by underground mining in the past and some coal has been worked opencast in recent years. The area has been described by Trotter and Hollingworth (1932).

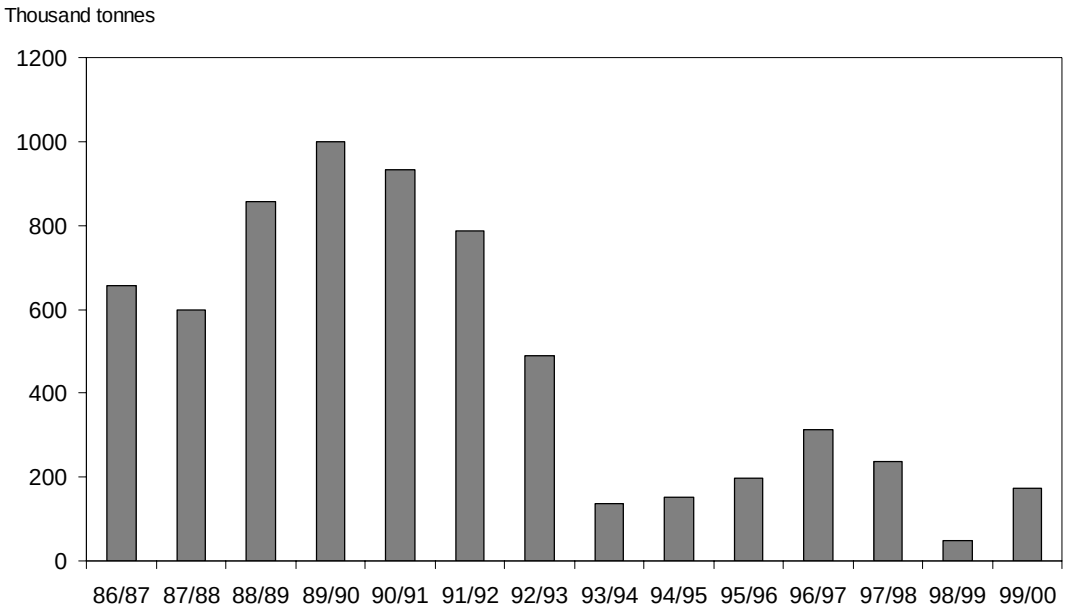


Figure 3. Opencast coal output in Cumbria by financial year, 1986-2000.
Source: *Opencast Coal Mining Statistics and the Coal Authority*.

Large-scale opencast coal mining began in west Cumbria in 1958 at Broughton Moor near Workington. Since then several large sites have worked coal from previously unworked portions of seams, from pillars of coal left as support in old workings and from a number of seams, mainly high in the Middle Coal Measures which had hitherto been little worked. Opencast mining is currently being carried out at the Keekle Head site, near Distington. Considerable scope exists for future opencast exploration and mining. Opencast coal typically has chlorine contents of 0.04–0.08 per cent, and 1.2–3 per cent sulphur (Michener and Barnes, 1999).

Whereas the Coal Measures rocks of west Cumbria are the county's best known source of workable coal, from which by far the largest tonnages have been extracted, a smaller but significant coal production has also come from seams lower in the Carboniferous succession. Most important of these lower seams is the Little Limestone Coal, which lies beneath the limestone of that name in the Caldbeck and Alston areas. Locally it has been extensively

worked in both areas and is currently mined underground in the Alston area, although only the small Clarghyll Colliery is in Cumbria. Throughout much of its outcrop in Cumbria the Little Limestone Coal is a bituminous coal commonly around 0.5 m thick, though it is thicker locally in the Alston area. In this latter area, where the coal has suffered some devolatilisation due to the relatively high heat flow above the concealed Weardale Granite, it is of a higher rank and is worked as a semi-anthracite. A seam, known as the Udale Coal, which occurs locally several metres below the base of the Coal Measures in west Cumbria, has been worked in places. Other pre-Coal Measures coals are very few, thin and have been little worked.

Areas of opencast coal extraction

The Coal Authority is a non-departmental public body which was established by the Coal Industry Act 1994. On 31st October 1994 it assumed responsibility for all the interests previously vested in British Coal in respect of unworked coal and coal mines and for the liabilities associated with past coal mining and unworked coal. The main functions of the Authority are to manage the coal resources under its control, encourage economically viable operations to work these resources, grant licences for coal exploration and extraction, provide effective management of subsidence damage claims, and provide information on past, present and proposed future coal mining activities.

For active sites, the extent of the licence area for coal extraction issued by the Coal Authority is shown. Licences in Cumbria are for both underground and opencast coal. Areas of extracted opencast coal are shown on the map, although these data may not be completely up-to-date. The Coal Authority's mining reports database contains information on past opencast coal mining activity, which is an aggregate of information derived from a number of sources. The areas shown on the map mainly reflect the limits of coal extraction. However, the recent entries into the mining reports database principally reflect site boundaries. No claim is made for the accuracy or completeness of the information. More detailed information on specific sites may be obtained from the Coal Authority (Appendix 2) and Cumbria County Council.

The economics of coal extraction has changed with time, allowing coal with higher overburden ratios to be extracted. Some sites, or parts of sites, have been worked on more than one occasion and may be worked for deeper coal in the future. However, modern sites worked within the last 20 years are likely to have exhausted the recoverable coal present.

CRUSHED ROCK AGGREGATE

Limestone is the principal source of crushed rock aggregate in Cumbria, but it is also worked on a significant scale for industrial purposes (Figure 1). In addition, igneous rocks and hard sandstones are relatively widespread and some are sufficiently extensive, with desirable physical and mechanical properties, to form potential sources of crushed rock aggregates. Location relative to markets is an important factor with respect to resource potential and many Cumbrian hard rock deposits are too remote for commercial extraction. Many are also located within the National Park. The production costs for igneous rock and sandstone aggregates are higher than that for limestone, which is hence the preferred material for general purpose aggregates. Some igneous rocks and sandstones are the source of high-specification aggregates for road surfacing. This is due to their higher abrasion and polish resistance. Production of crushed rock for the period 1979–1999 is shown in Figure 4.

Limestone

Cumbria is an important source of limestone and in 1999, 4.4 million tonnes were quarried in the county, representing approximately 5 per cent of national output. Most is consumed in the construction industry as aggregate or fill for local and regional needs. Significant amounts of industrial (high purity) limestone are produced for steel and chemical uses, and lime for the steel industry is an important product of Hardendale Quarry, Shap. The quarries in the south of the county, which have good motorway access, distribute aggregate materials as far south as Manchester and Liverpool.

Limestone is an important component of the geological sequence in Cumbria. Large-scale extraction is restricted to limestones of Carboniferous age and it is these rocks which comprise the present and future resources of this mineral in Cumbria. Limestones comprise a major proportion of much of the lower part of the Carboniferous succession of Cumbria. They give rise to the distinctive and attractive landscapes of much of southern Cumbria, parts of west Cumbria and the dales scenery of the Pennines.

Most of the Carboniferous limestones of Cumbria are of Lower Carboniferous (Dinantian), age, although one major unit, known in different parts of the county as the First, Great, Main or Catsbit limestone, forms the lowest unit of the Upper Carboniferous (Namurian) sequence.

The Lower Carboniferous succession of Cumbria varies markedly both in the rock types present and in overall thickness from place to place throughout the county. These variations reflect differences in

the environments in which the rocks were deposited during Carboniferous times.

During Lower Carboniferous times, about 360 and 300 million years ago, the area that was to become Cumbria lay within tropical latitudes and was submerged beneath a wide, shallow tropical sea into which a number of large rivers periodically poured sand and mud. Within this sea the remains of a wealth of calcareous organisms accumulated to form beds of limestone. Periodic influxes of sand and mud, brought into the sea by rivers, mainly from the north, are today preserved as beds of sandstone and mudstone respectively. Short-lived periods of plant-growth, which developed on these sands and muds, are locally preserved as thin coal seams. Over much of west and south Cumbria limestone formation throughout the Lower Carboniferous period was generally uninterrupted for long periods, leading to the accumulation of thick and locally very pure beds of limestone. Further to the north and east influxes of other sediment were more frequent, giving rise to the characteristic regular alternations of limestones with sandstones, mudstones and, locally, thin coals. These are commonly referred to as 'Yoredale' cyclothems from their characteristic development in Wensleydale, North Yorkshire. Yoredale is an old name for Wensleydale.

The Mineral Resource Map defines only those limestone units with a consistent thickness of more than 10 m: numerous thinner limestones have been omitted. For much of the county the limestone nomenclature used is that employed on the currently available BGS 1:50 000 or 1:63 360 sheets. For the area between Shap and Ravenstonedale, and in parts of the Kendal and Kirkby Lonsdale area, where modern BGS mapping is not yet available, the limestone outcrops are based on the work of Garwood (1912), modified in places by Harrison et al (1991). Limestone formations which can be defined as 'high purity limestone' (>97 per cent $CaCO_3$) (Harrison et al, op cit) are identified separately. It has not proved feasible to attempt estimates of overburden thickness, either of overlying 'solid' formations, or of superficial or 'drift' deposits. The map therefore shows the surface and subdrift outcrop only of limestone units.

The main resources lie to the west and south-west of the Eden Valley where Carboniferous limestones form a discontinuous outcrop around the Lake District. To the east of the Eden Valley, along the Pennines escarpment, the limestone beds are relatively thin and interbedded with sandstone and mudstone. One of the most prominent limestones extends into Northumberland, Durham and Yorkshire.

Carboniferous limestones crop out in six main resource areas; in south Cumbria in the Furness, Grange over Sands, Milnthorpe,

Kirkby Lonsdale and Kendal areas; in central areas between Ravenstonedale and Penrith; in west Cumbria; between Caldbeck and Penrith; in the Pennines and in north Cumbria. In each resource area, the limestones are different in their character and thickness and have been given a complex series of stratigraphical names. The geology and resource potential of each area are described below.

South Cumbria

The limestones, which form prominent fault-bounded blocks, have been divided into a number of rock units (Table 1). Most are ideally suited to the production of good quality aggregates, although some formations contain mudstone bands and sandy beds. The Basement Beds are dominated by conglomerate, sandstone and mudstone which infill irregularities in the ancient Lower Palaeozoic platform. The uppermost unit, the Gleaston Formation, is mostly dominated by mudstone with thin sandstones and only thin limestones. These formations are, therefore, not shown on the map. All other formations are capable of producing strong, low porosity limestone aggregates. Notable high purity (>97% $CaCO_3$) units are the Red Hill Oolite, Park Limestone and Urswick Limestone. All three formations contain substantial thicknesses of high purity limestone and form important resources of industrial grade limestone. The Park Limestone is particularly uniform in lithology and chemistry. However, the Martin Limestone and Dalton Beds are chemically variable due to the presence of mudstone beds, patchy silicification and dolomitisation.

The Urswick Limestone is the most actively quarried unit, particularly in the south of the area where extraction is mainly for aggregate production. Some industrial limestone, as well as aggregates, is produced from the Park and Urswick limestones near Dalton-in-Furness.

Table 1. Carboniferous Limestone succession in south Cumbria (Rose and Dunham, 1977)

Gleaston Formation	25 – 200 m
Urswick Limestone	120 – 160 m
Park Limestone	120 – 130 m
Dalton Beds	110 – 255 m
Red Hill Oolite	60 m
Martin Limestone	25 – 135 m
Basement Beds	0 – 240 m

Penrith - Ravenstonedale outcrop

Limestones dominate the Lower Carboniferous succession of this area. Modern BGS mapping of this area is not yet published. The outcrops depicted on the resource map are adapted by Harrison et al, (1991) from the work of Garwood (1912).

The Carboniferous Limestone surrounding the eastern Lake District was deposited in a different sedimentary environment (of deeper water sedimentation) from the shallow-water shelf sequence previously described for south Cumbria. The limestone sequence is much thicker than in the southern outcrops and is significantly different in lithology. A different stratigraphical scheme is used to describe the succession (Table 2), although it is possible to correlate certain formations. It is only in the strata above the Ashfell Sandstone (equivalent to the upper part of the Dalton Beds) that the lithostratigraphy is similar to the more southerly outcrops.

Table 2. Carboniferous Limestone succession in the Ravenstonedale–Penrith area

Upper Alston Group	130 – 260 m
Knipe Scar Limestone	60 – 140 m
Potts Beck Limestone	0 – 70 m
Ashfell Limestone	40 – 180 m
Ashfell Sandstone	70 – 190 m
Michelinia Grandis Beds	30 – 130 m
Scandal Beck Limestone	35 – 120 m
Coldbeck Beds	30 – 70 m
Stonegill Beds	35 – 100 m
Basement Beds	10 – 35 m

The Basement Beds consist of conglomerate and shaly sandstone, and the sequence below the Ashfell Sandstone mostly consists of well bedded, shaly limestone. Locally, around Shap, the lower part of the limestone sequence is extensively dolomitised and termed the Shap Dolomites. The Ashfell Sandstone is a series of fine-grained quartzitic sandstones with interbedded limestones. Thin beds of sandstone and mudstone also occur in the overlying Ashfell Limestone which is also partially siliceous and cherty. The Ashfell Limestone is equivalent to the Park Limestone of the Furness district.

The limestones of the Knipe Scar Limestone form strong scar features and are the equivalent of the Urswick Limestone of Furness. They are similarly composed of pale grey, thick-bedded limestones with prominent bedding planes marking the horizons of mudstone bands. A particularly thick (5–10 m) mudstone and sandstone band is present in the upper part of the formation. The Upper Alston Group is a sequence of alternating thin limestone, mudstone and sandstone with coals (the so-called ‘Yoredale facies’). Nine persistent thin limestones (averaging 9 m in thickness) are recognised and are characterised by particular lithologies. The proportion and thickness of mudstone and sandstone increases in a north-easterly direction. To the north of Shap the overlying Namurian strata contain one relatively thick limestone, the Great

Limestone, in the lower part of the succession. The Great Limestone is between 10–20 m thick and consists of mid-grey, thin-bedded limestones with mudstone partings.

The most consistently pure limestone in this area is the Knipe Scar Limestone which has been extensively quarried at several sites. It is actively quarried at Hardendale Quarry near Shap, producing lime for steelmaking as well as aggregates. The limestone contains small amounts of silica, alumina and iron oxides but most of the sequence can be classified as high purity (>97% $CaCO_3$). The presence of interbedded mudstone may result in some chemical variability and in parts of the sequence where these thicken and include sandstone, they may form up to 25 per cent non-mineral (waste material). The limestones produce good quality aggregates (Table 3). The Potts Beck Limestone has also been identified as a high purity limestone. The limestone resources of other parts of the sequence are of mixed quality, reflecting the shaly and variable nature of the limestones. There is currently no active limestone quarrying in beds below the Ashfell Limestone. Some small-scale quarrying for building stone takes place from the Ashfell Limestone and also from limestones in the Upper Alston Group, although in general these are too thin to support a modern quarrying operation and are not shown on the map.

Table 3. Typical aggregate test data from Carboniferous limestones in Cumbria

Formation	Location	PSV	AAV	AIV	ACV	TFV	RD	WA
Great Lst	Penrith	43	8.1	20	19	250	2.68	0.8
Fourth Lst	Whitehaven	43	8.5	19	23	190	2.70	0.7
Knipe Scar Lst	Shap	34	-	22	21	200	2.62	0.9
Urswick Lst	Grange	44	9.4	20	19	230	2.68	0.8
Urswick Lst	Burton	36	10.9	20	24	170	2.68	0.2
Park Lst	Barrow	41	14.7	21	23	140	2.61	2.0

Definitions:

Aggregate Abrasion Value (AAV): Resistance of an aggregate to abrasion as measured in the aggregate abrasion test. The smaller the value the more resistant the rock is to abrasion. Abrasion resistance is particularly important for road surfacing materials.

Aggregate Crushing Value (ACV): Resistance of an aggregate to crushing when subjected to a crushing force as measured by the aggregate crushing test. The smaller the value, the more resistant the rock is to crushing.

Aggregate Impact Value (AIV): Resistance of an aggregate to repeated impact as measured by the aggregate impact test. The smaller the value, the more resistant the rock is to impact.

Polished Stone Value (PSV): Resistance of an aggregate to polishing as measured in the accelerated polishing test. A measurement of skid resistance on road surfaces. The larger the value the more resistant the rock is to polishing.

Ten per cent fines value (TFV): Resistance of an aggregate to crushing as measured by the force in kN applied in the ten per cent fines value test. The larger the value, the more resistant the rock is to crushing.

Relative density (RD): The density of a rock compared with that of water.

Water absorption (WA): Percentage of water by mass that can be absorbed by an aggregate when in a saturated surface-dried condition.

West Cumbria

Limestone dominates the approximately 200 m of Lower Carboniferous strata in west Cumbria between Whitehaven and Cockermouth. The naming of individual limestone units (Table 4), in descending order from the Second down to the Seventh limestone, recalls the days of iron ore mining when successively lower limestones were encountered in shaft sinking and mine development. The uppermost of the west Cumbrian limestones, the First Limestone, is the lowest unit of the overlying Upper Carboniferous (Namurian) succession.

Throughout much of this area beds of mudstone with sandstone between the limestones comprise a comparatively small proportion of the succession, though these beds are rather thicker between the Third, Second and First limestones, particularly towards the north-east of the area around Cockermouth. Normally these are less than 3 m thick, although locally they may attain 10 m or more. The limestones are thick-bedded and dark to pale grey in colour. Locally they contain shaly layers and thin bands of chert. Although the limestone sequence is more argillaceous than in areas to the east and south, many parts of the sequence contain relatively consistent limestone units suitable for producing general purpose aggregates for construction. Purity is variable, but the Fourth Limestone and, in particular, the White Limestone form a consistent sequence of pale grey limestones and represent the purest limestone deposit in the area. The limestones of west Cumbria host the extensive hematite mineralisation of the west Cumbrian orefield. Mineralisation with hematite, dolomite, baryte and other minerals typical of the ore deposits, adjacent to the faults and joints, is common in many

quarries and outcrops. A distinctive brown alteration of limestone is locally a significant contaminant adjacent to faults and joints.

Table 4. Carboniferous Limestone succession in the west Cumbria–Penrith area

U Carboniferous (Namurian)	First (Great) Limestone	up to 20 m
	Second Limestone	up to 10 m
	Orebank Sandstone	20–60m
L. Carboniferous	Third Limestone	up to 5 m
(Dinantian)	Fourth Limestone (inc. White Lst. in lowest part)	up to 70 m
	Fifth Limestone	up to 20 m
	Sixth Limestone	up to 15 m
	Seventh Limestone	up to 60 m
	Basement Beds	Variable thickness

Table 5. Typical chemical properties of high-purity limestones in Cumbria

Formation	Locality	CaO	MgO	SiO_2	Fe_2O_3	Al_2O_3
				Wt %		
Great Scar Lst	Brough	52.21	0.17	3.50	0.20	0.07
Robinson Lst	Brough	55.05	0.27	2.06	0.06	0.00
Knipe Scar Lst	Shap	55.93	0.22	0.43	0.08	0.05
Urswick Lst	Grange	55.35	0.27	0.12	0.03	0.00
Park Lst	Grange	55.52	0.36	0.00	0.02	0.00
Park Lst	Barrow	55.74	0.14	0.00	0.00	0.00
Red Hill Oolite	Grange	55.73	0.57	1.24	0.10	0.03

Caldbeck–Penrith area

In this area the Lower Carboniferous limestones, up to and including the lowest part of the Fourth Limestone, of the west Cumbrian succession are recognised (Arthurton and Wadge, 1984). Above this, limestones occur as components of a regularly alternating sequence of limestone, mudstone, sandstone and, locally, thin coal. The highest limestone, the First Limestone, here, as in west Cumbria, comprises the lowest unit of the Upper Carboniferous (Namurian) succession. These limestones may be correlated with those of the Pennines. Although up to nine limestones may be distinguished in this part of the sequence, only four normally reach or exceed 10 m in thickness and only these are shown on the map.

The lithological characteristics of the lower limestones here closely match their counterparts in west Cumbria. The higher limestones are typically medium to dark grey limestones. Thin mudstone partings are common, especially within the First Limestone.

Table 6. Carboniferous limestones in the Caldbeck–Penrith area shown on the resources map with approximate thicknesses.

U. Carboniferous (Namurian)		First Limestone	up to 30 m
		Four Fathom Limestone	up to 12 m
		Tynebottom Limestone	up to 10 m
		Jew Limestone	up to 10 m
L. Carboniferous (Dinantian)	Fourth Lst.	Rough Limestone	up to 10 m
		White Limestone	up to 25 m
		Fifth Limestone	up to 45 m
		Sixth Limestone	up to 40 m
		Seventh Limestone	up to 60 m

Table 7. Carboniferous limestones in the Pennines area shown on the resource map with approximate thicknesses.

U. Carboniferous (Namurian)	Great Limestone (= Main Limestone)	up to 20 m
	Four Fathom Limestone (= Undersett Limestone)	up to 10 m
	Upper Scar Limestone	up to 15 m
	Tynebottom Limestone	up to 10 m
L. Carboniferous	Jew Limestone	up to 10 m
(Dinantian)	Smiddy Limestone	up to 10 m
	Peghorn Limestone	up to 14 m
	Lower Robinson Limestone	up to 20 m
	Melmerby Scar Limestone (= Great Scar Limestone)	40–100 m

Pennines

The Lower Carboniferous succession of the Pennines resembles that outlined in the Caldbeck–Penrith area. Thick limestone units, known as the Melmerby Scar Limestone in the Northern Pennines, and its equivalent the Great Scar Limestone of the Yorkshire Pennines, are overlain by a well developed 'Yoredale' succession comprising regular cyclical units of limestone, mudstone, sandstone and locally thin coals (Burgess and Holliday, 1979; Dunham, 1990). The Great Limestone of the Northern Pennines, known as the Main Limestone in the Yorkshire Pennines, and the correlative of the First Limestone of west Cumbria, forms the lowest unit of the local Upper

Carboniferous (Namurian) succession. Most of the limestones known in this succession are less than 10 m thick and are thus excluded from the resource map. Typically these Pennine limestones are well bedded, medium to dark grey limestones, commonly with thin mudstone partings. Thicker limestone beds are seen only in a narrow belt along the Pennine escarpment. The Great Scar Limestone is quarried on a more extensive scale for aggregates at Kirkby Stephen and the Robinson Limestone is extracted for aggregates and building stone near Brough. The Great Scar, Melmerby Scar and Robinson limestones are likely to be mainly of high purity (>97% $CaCO_3$). Other limestone units are mostly of moderate or lower purity.

Mineralisation is locally a minor contaminant of limestone adjacent to some faults and joints.

North Cumbria

Although limestones are common in the Carboniferous rocks of north Cumbria most are too thin to be considered as a limestone resource. The only Lower Carboniferous limestones which locally reach or exceed 10 m in thickness are (in ascending stratigraphical order) the Penton or Greengate Well Limestone, the Harelawhill Limestone and the Buccleugh Limestone (Day, 1970). These crop out in a very restricted area of structural complexity close to the Scottish Border in the Liddel Water. The Catsbit Limestone, the lowest unit of the local Upper Carboniferous (Namurian) succession, and thus the correlative of the First, Great and Main Limestones elsewhere in the county, also has a small outcrop in this area. Like its equivalents elsewhere it is up to 20 m thick and comprises medium grey limestone with thin mudstone partings.

Elsewhere thin, and generally impure, limestones of Ordovician, Permo-Triassic and Jurassic age also occur and many of these have been worked on a small scale for local use in the past. However, they are too thin to be considered a limestone resource and are not shown on the Mineral Resources Map.

Igneous and metamorphic rocks

The various Lower Palaeozoic igneous rocks in the area provide an important resource of crushed rock aggregate. They can be divided into two main categories: fine-grained, mainly volcanic (extrusive) rocks, and medium and coarse-grained, mainly intrusive rocks. The former comprise the very thick sequences of volcanic rocks, which occur at the northern margin of the Lake District (the Eycott Volcanic Group) and more extensively in the central part of the Lake District (the Borrowdale Volcanic Group). The Borrowdale Volcanic Group covers an area of about 848 km^2 and gives rise to the most spectacular scenery in the region. Its outcrop is almost entirely within the boundaries of the Lake District National Park.

The Borrowdale Volcanic Group consists of a complex sequence, mainly of andesite, tuff (lithified fragments of volcanic ash less than 2 mm across) and sedimentary rocks composed of volcanic detritus of various size ranges. The complex lithological variability of these volcanic rocks results in variable rock properties, including the development of slate (see below). The volcanic rocks have been little worked as a source of aggregate. Andesite and basalt constitute much of the Eycott Volcanic Group and the lower part of the Borrowdale Volcanic Group. Andesite and pyroclastic rock from the Furness inlier in south Cumbria were formerly quarried at Greenscoe. Tuffs are a major constituent of the upper part of the Borrowdale Volcanic Group and certain types, such as the coarser welded tuffs, are capable of producing high specification aggregates with very high polished stone values (65). This material is quarried at Ghyll Scaur, near Millom for road surfacing materials. Knock Pike Quarry in the Cross Fell inlier is located in a similar rock type and is also in the upper part of the Borrowdale Volcanic Group, but is no longer worked

A variety of fine, medium and coarse-grained intrusive igneous rocks also occur, some of which have been used in the past for crushed rock aggregate and ornamental stone. The largest intrusions are the medium- and coarse-grained granitic rocks of the Eskdale and Ennerdale granites of the western Lake District. Smaller bodies include the Shap Granite, in the east, which has been used for crushed rock and ornamental purposes, the Threlkeld Microgranite which was worked as a source of aggregate until 1980, and the Skiddaw Granite. The rocks surrounding these intrusions were altered by heat during emplacement of the igneous bodies, producing a metamorphic rock known as hornfels. In particular, volcanic rocks (andesite) around the Shap Granite have been altered in this manner to a hard durable hornfels suitable for aggregate, which is extensively quarried at the Shap Blue Quarry. This rock is much harder than the pink granite (Table 8) and is quarried to produce an aggregate suitable for road surfacing materials, concrete products and railway track ballast. It has a particularly high abrasion resistance and high relative density. The nearby Shap Granite is now intermittently worked primarily for dimension stone.

Intrusive basic igneous rocks occur on Carrock Fell (gabbro) and around Haweswater (gabbro and dolerite). In addition, there are numerous smaller intrusions of diorite, (formerly worked at Embleton), dolerite and basalt, including the Whin Sill which crops out along the Pennine escarpment and near Brampton. The Whin Sill is an important source of aggregate elsewhere in northern England, but in Cumbria it is relatively thin and of limited potential.

Table 8. Properties of some igneous, metamorphic and sandstone aggregates in Cumbria

Rock type	Locality	PSV	AAV	AIV	ACV	TFV	RD	WA
Shap Granite	Shap	54	3.4	23	25	150	2.69	0.6
Hornfels	Shap	55	1.4	9	10	380	2.83	0.5
Borrowdale V G	Millom	65	6.0	19	23	190	2.70	0.7
Silurian Sst	Kendal	62	7.5	15	16	310	2.71	0.7

The extensive, but variable, nature of the Borrowdale Volcanic Group means that only parts will be suitable as sources of high quality aggregate. The full extent of the group is shown on an inset map and only those units in proximity to existing or former quarries are shown on the main map. The outcrops of the Eskdale and Ennerdale intrusions, together with most of the smaller intrusive bodies, are also only shown on the inset map because of their generally remote location. The Shap Granite and its associated thermal aureole are, however, shown on the main map because of their proximity to major transport links.

Sandstone

Sandstones are accumulations of sand-sized particles composed predominantly of quartz, with variable amounts of feldspar and rock fragments set in a fine-grained matrix or cementing material. Many sandstones are very variable in quality and are often interbedded with mudstone or siltstone, or are weakly cemented. Relatively few sandstones form important aggregate resources.

Sandstones were traditionally valued as a source of building stone, and small amounts are still produced for this purpose in Cumbria (see below). However, they are now valued principally as a source of aggregate and this is by far their largest use, both nationally and within the county.

The suitability of a sandstone for aggregate use mainly depends on its strength and durability. Many sandstones are too weak and porous to be used other than as a source of constructional fill. However, more indurated and higher strength sandstones are suitable for more demanding aggregate uses, such as concrete aggregate and roadstone.

The variations in the aggregate properties (and thus aggregate potential) of sandstones are related to differences in composition, grain size, texture, colour, burial history and tectonic setting, metamorphism and weathering. Individual sandstones also vary in thickness and lateral persistence. In general, older more indurated sandstones exhibit higher strengths, except where they are weathered. Compositional differences, both of sand grains and the

matrix, give rise to a range of rock names under the general heading of sandstone. Hard sandstone containing mineral and rock fragments cemented in a clay matrix is referred to as greywacke. This rock is typically highly resistant to polishing (very high PSVs), due to the range in hardness of the constituent grains, which results in a high degree of surface roughness. In addition, where greywackes have been affected by tectonic compression their strength and abrasion resistance has often been substantially improved. They are, therefore, particularly valued as sources of high quality, skid-resistant aggregates used for road surfacing (so-called high specification aggregates), which are the premium products of the crushed rock quarrying industry.

Sandstone (greywacke) occurs both within parts of the Skiddaw Group and more extensively within the Windermere Supergroup, where units of this rock are locally capable of producing relatively strong and durable aggregates. The Ordovician Skiddaw Group comprises the oldest rocks in Cumbria and occurs principally in the northern Lake District. The group consists mainly of mudstone and siltstone with some sandstone, but these have not been worked as a source of aggregate and are not shown on the mineral resources map. Rocks of the Windermere Supergroup, of late Ordovician and Silurian age, crop out mainly in the southern Lake District. The succession is principally dominated by interbedded mudstone, siltstone and sandstone. The thickest accumulations of sandstone are included in the Coniston Group (formerly the Coniston Grits) and the Kirkby Moor Formation, and the extent of these is shown on the map. A sandstone within the Wray Castle Formation exposed in the Kirkby slate quarry near Kirkby-in-Furness has been identified as having a high PSV (62) (Thompson et al., 1993). Greywacke sandstones within the Kirkby Moor Formation are quarried at Holmescales and Roan Edge, near Kendal, for a range of aggregate uses, including skid resistant road surfacing materials (Table 8).

Sandstone units of younger geological age in Cumbria are generally too soft for use as crushed rock aggregates but some are quarried for building stone (see below).

SAND AND GRAVEL

Although conveniently grouped together, sand and gravel are separate commodities. The term 'gravel' is currently used for material which is coarser than 5 mm, with a maximum size of 40 mm, and the term 'sand' to material that is finer, but coarser than 75 μm. The principal uses of sand are as fine aggregate in concrete, in mortar and in asphalt, and the main use of gravel is as coarse aggregate in concrete. Sand and gravel production in Cumbria was some 785 000 tonnes in 1999. Production since 1979 is shown in Figure 4. Sand and gravel resources occur in a variety of geological environments in Cumbria.

All occur within those deposits classified as superficial or 'drift' deposits. These were formed within the last two million years; some, such as marine beach sands are still being accumulated. For the purposes of this assessment these have been grouped into the following four broad categories:

- River sand and gravel
- Glacial sand and gravel
- Marine (Beach) sand and gravel
- Blown sand

For clarity, the distribution of sand and gravel resources is shown on a separate map. The variability of sand and gravel deposits together with their possible concealment within or beneath till (boulder clay), means that, compared with other bulk minerals, it is more difficult to infer the location and likely extent of potentially workable resources from geological maps. The properties which influence the economic potential of a sand and gravel deposit include:

- sand to gravel ratio
- proportion of fines and oversize material
- presence of deleterious rock types (such as coal or mudstone)
- thickness of deposit and overburden ratio
- position of the water table
- possible presence of unwanted interbedded material
- the ease with which material can be processed to produce a saleable product (clay fines are more difficult to remove than silt)
- location relative to demand

The principle adopted in compiling the sand and gravel resource map has been to depict all mapped outcrops of the four main categories of deposit.

With the exception of parts of the Brampton area in the north of the county, where specific studies of sand and gravel resources have been undertaken, no data are available that allow the delineation of areas of specific properties or quality (Jackson, 1979). Insufficient data exist to attempt meaningful estimates of gross tonnage.

River sand and gravel

Included in this category are deposits depicted on BGS maps as Alluvium, River Terrace Deposits and Alluvial Fan Deposits.

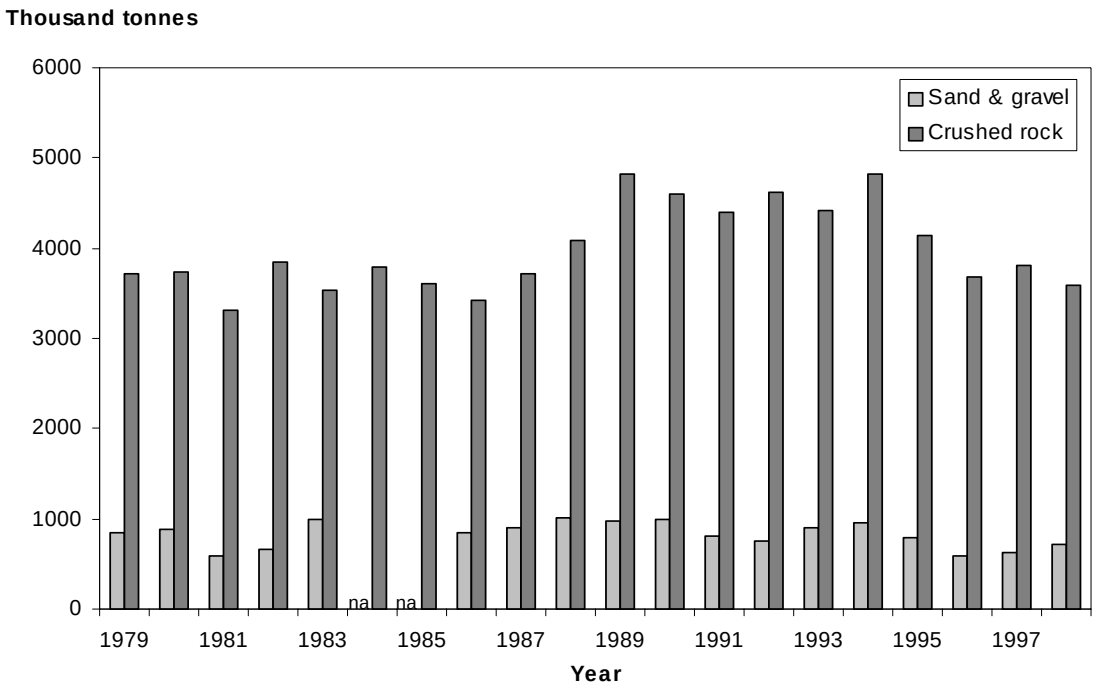
Alluvium covers a wide range of river-laid deposits which may range in composition from fine silt and clay, through sand to coarse gravel, including sub-alluvial gravels beneath an overburden of finer grained sediments. The character of the materials present, and their distribution within any area of alluvium may be extremely variable

and complex and reflects the nature of source materials and the conditions which controlled their transport and deposition within the river system. River sand and gravel deposits are worked at Cardewmires Quarry, south west of Carlisle.

River Terrace Deposits occur at various levels above the present day level of the alluvial flood plain. They represent the eroded remnants of formerly more extensive, relatively gravel-rich alluvial deposits laid down adjacent to rivers during periods of higher base level during post-glacial times. Such deposits commonly resemble those mapped as alluvium. Like these they may contain significant concentrations of sand and gravel.

Alluvial Fan Deposits comprise a variety of alluvial materials deposited as deltas at a break in slope adjacent to the confluence of a tributary stream with a main valley. Such deposits are typically of limited extent. Like other alluvial sediments these may locally contain significant proportions of sand and gravel and, where they occur adjacent to substantial areas of alluvium, river terrace, or other likely sand and gravel resources are included with these deposits.

Insufficient data exist in the BGS archive to attempt a systematic assessment of the likely sand and gravel content of any of these deposits within Cumbria. The areas shown in the accompanying map include the more extensive areas of alluvium, river terrace and those alluvial fan deposits which, from a general consideration of the local solid and drift geology, may reasonably be expected to offer the conditions for the presence of some concentrations of sand and gravel. Areas of such deposits adjacent to, or substantially sourced from, pre-existing deposits of sand and gravel, such as glacial sand and gravel, may, at least locally, contain a significant sand and gravel component.



na - not available

Figure 4. Crushed rock and sand & gravel production in Cumbria, 1979-1999
Source: ***Annual Minerals Raised Inquiry. Office for National Statistics.***

Glacial sand and gravel

BGS 'drift' maps customarily depict outcrops of sand and gravel interpreted as having been deposited by glacial meltwater. On older maps these are generally described as 'glacial sand and gravel' though on more recent maps the terms 'glaciofluvial' and 'fluvioglacial' have been applied to such deposits as a better indication of their nature and origin.

In Cumbria, as in most parts of Britain, the sequence of glacial and post-glacial deposits is typically complex. Individual mappable units commonly exhibit intricate and complex relationships with one another. This is particularly true of sand and gravel deposits. These may occur as sheet-like or delta-like layers above boulder clay or till deposits or may occur as elongate or irregular lenses within the till sequence. The three-dimensional form of any sand and gravel body may be extremely difficult or impossible to determine from field evidence alone, and even with some borehole data its form may, at best, be regarded as conjectural. Many outcrops of glacial sand and gravel may occur as isolated masses underlain by other deposits. Others may be the surface manifestation of more extensive bodies which pass beneath other drift deposits. Areas of wholly concealed, and thus unknown, bodies of glacial sand and gravel may occur under extensive spreads of till and other drift deposits. Such concealed bodies may be very large though their presence and likely extent can only be determined by detailed exploration methods such as closely spaced drilling. Glacial sand and gravel deposits are

worked at several locations within the county, for example at Peel Place Quarry, near Ravenglass and Faugh No1 Quarry in the Brampton area.

The accompanying map shows only exposed areas of glacial sand and gravel depicted on BGS maps. Except in very limited areas in the Brampton area, insufficient data exist in BGS archives to attempt reliable predictions of the extent of any concealed glacial sand and gravel resources. In any consideration of sand and gravel resources the possibility of concealed extensions of mapped outcrops, or of the presence of wholly concealed deposits beneath the till (boulder clay), should be considered.

Areas of boulder clay may have potential, not only as a cover for concealed deposits of sand and gravel, but locally for rather less clearly defined sandy and gravely portions of the boulder clay itself.

Marine (beach) sand and gravel

Included in this category are those sand and gravel deposits which comprise the modern beaches, mapped on the most recent BGS maps as 'Shoreface and Beach Deposits', together with 'Storm Beach Deposits' and a variety of raised beach deposits. Typically these deposits comprise accumulations of sand and gravel, and are restricted to the modern coast and a relatively narrow belt of country adjacent to it. It excludes offshore deposits. Beach deposits are worked at South Walney on Walney Island.

Rather more extensive spreads of 'Raised Marine Deposits of Flandrian Age', mapped on the north coast of Morecambe Bay in the Ulverston area may include local concentrations of sand and gravel, though their extent is not reliably known.

Blown sand

Coastal dunes, composed of wind-blown sand, occur along parts of the Solway coast, near Ravenglass and at Walney Island. Whereas large tonnages exist in some of these deposits, little or nothing is known of the quality of the sand, although these are likely to be fine-grained. The extensive spreads of blown sand in the Ravenglass area lie mainly beneath a National Nature Reserve and armaments proving ground.

Miscellaneous superficial deposits

Small area of Moraine, Scree and Head may locally contain sand and gravel but their commercial suitability is not known and they have been excluded from the map.

BUILDING STONE

A wide range of rock types are used as sources of building stone. Their suitability depends not only on aesthetic qualities such as colour and textural consistency but also on factors such as strength and durability, together with commercial considerations such as the size of block or slab that can be extracted. A continuing supply of building stone from a variety of sources is important for new build and conservation work. Building stone producers range from small operations only supplying resources for the local construction market, to larger concerns that trade across the UK and sometimes overseas. A number of quarries that are primarily considered to be crushed rock producers have also developed a subsidiary but important trade in the production of building stone.

A wide range of igneous, metamorphic, and sedimentary rocks have been quarried in Cumbria for use as local walling stone, but a number have also been exploited on a more commercial basis.

Igneous rock

A variety of igneous rocks occur within the county and have been quarried for aggregate use, however, a few have also been worked as building or decorative stones. Most of the older buildings in the National Park are built of local stone, e.g. from the Borrowdale Volcanic Group. The Eskdale (pink) and Threlkeld (grey) granites have been widely used locally for wallstone. Small quantities of the grey granodiorite from the Eskdale intrusion at Broad Oak Quarry, Waberthwaite, have been used as a polished ornamental stone. The Shap granite quarries, on Wasdale Fell south of Penrith, have been in commercial operation since at least the mid 19th century. The coarsely crystalline, dark and light coloured varieties with their characteristic, large pink feldspars are still intermittently produced for decorative work.

Sandstone

Sandstones are a traditional source of building stone, and modest quantities of sandstone of various geological ages are produced in Cumbria.

The suitability of a sandstone for building stone depends not only on strength and durability, but also on aesthetic qualities and textural consistency, and the size of the blocks that can be produced. Thinly-bedded sandstones may be suitable for the production of flagstones and roofing slates. A continuing supply of building stone for new building work and for restoration is important to maintain local vernacular architecture. Quarries are usually small and are often based on resources of only local significance. For this reason the extent of the resources is not shown on the map.

Sandstones of Lower Palaeozoic age are now principally quarried for roadstone but in the past were widely used for wallstone as is evident in housing at, for example, Windermere and Ambleside.

Sandstones of Upper Palaeozoic (Carboniferous–Permian) and Triassic age are the principal sources of building sandstones quarried today in Cumbria. Upper Carboniferous sandstones were once worked extensively at Lamonby and Greystoke, west of Penrith, but are now only quarried near Nenthead.

Permian and Triassic sandstones are the principal sources of red building sandstone still worked in Britain. They exhibit a wide range of hues but are of varying durability. The Permian beds of the Penrith Sandstone have a long history of production (e.g. Penrith Castle - 15th century) and five quarries remain in operation near Penrith around Lazonby Fell.

The red sandstone beds of the Triassic St Bees Sandstone Formation are believed to have been quarried since at least the early 12th century, for use in Furness Abbey. Successful sandstone quarries operated at Aspatria, Barnetrigg (a white variety) and around Carlisle in the past. Today, four quarries are still in operation exporting red sandstone throughout Britain and overseas, notably to the USA. The working quarries are centred on the St Bees headland.

Limestone

Carboniferous limestones in the Kendal and Kirkby Lonsdale areas have been extensively quarried in the past for local building stone, much of which was used in these two towns. Today three quarries are working the limestone near Orton for building stone. Elsewhere fossiliferous beds of limestone are worked near Ulverston for decorative ‘marble’ and ashlar.

SLATE

The term ‘slate’ is applied to rocks that can be readily split, or cleaved, into thin sheets or slabs suitable for roofing or other architectural purposes. Slate is most commonly developed from fine-grained sedimentary rocks, such as mudstones, which have developed a well marked slaty cleavage due to the crystallisation and realignment of platy minerals within the rock mass. It is along this cleavage that the rock can be split, thus giving it its economic importance. Bodies of slate generally have a restricted occurrence within more extensive masses of less perfectly cleaved rock, which accounts for the large tips of waste commonly associated with the slate industry.

Slate was formed across wide areas of the Lake District about 400 million years ago during a mountain building episode which

caused intense compression of the Lower Palaeozoic rocks and the development of a slaty cleavage in the finer grained rocks. Commercial operations in the Lake District, stretching back some 2000 years, have concentrated on the extraction of two distinct products. The most famous of these is the 'Lakeland green slate' obtained from the volcanic rocks of the Borrowdale Volcanic Group in the central part of the Lake District. A very even and regular cleavage in the fine-grained and lithologically uniform mudstones of the Windermere Supergroup produce what is referred to locally as 'blue-grey slate.' These rocks form the principal slate resources and are shown on the Mineral Resources map.

Lakeland green slate is obtained from intensely cleaved volcanic mudstone, siltstone and sandstone. These rocks occur in thick units at many levels in the Borrowdale Volcanic Group, but they form a significant proportion of the upper part of the succession. Small workings are visible on the hillsides throughout the outcrop of the Borrowdale Volcanic Group, testifying to their former extraction as walling and roofing materials. However, the natural colours and variety of textures present on prepared surfaces of the volcanic sandstones and siltstones make the green slate much sought after for architectural and ornamental purposes. The attractive patterns seen both on riven, and on cut and polished surfaces reflect the great variety of sedimentary structures and changes in grain size present in these rocks.

The resource areas shown on the maps have a number of limitations. Firstly, they are generally of rock at or near surface. Locally, and particularly in the major valleys, the resource may be covered by substantial drift (>10 m; mainly glacial and river deposits). Secondly, the intensity of the cleavage varies across the volcanic outcrop. Further, some of the rock types within the resource formations may not be fit for purpose, for example because the cleavage is not sufficiently regular or intense. Some of these rocks may be suitable for wire-sawn architectural products, rather than roofing material. Thirdly, many of the volcanic sandstone units within the Borrowdale Volcanic Group contain intrusions, mainly of andesite. The larger of these have generally been omitted from the resource map, though smaller intrusions may have been included in the resource areas.

Substantial resources of Lakeland green slate occur around Honister Pass, between Buttermere and Borrowdale, and in parts of Borrowdale. These are from the Eagle Crag Member, a locally persistent unit within the lower part of the Borrowdale Volcanic Group. The most extensive slate belt is seen in the southern part of the outcrop of volcanic rocks, from south-west of Coniston at Broughton Moor north-eastwards to The Old Man of Coniston, Tilberthwaite, Elterwater, and Chapel Stile to Kirkstone (Petts Quarry). The very extensive network of workings in these areas,

including most of the currently active quarries, occurs within the Seathwaite Fell Formation, a widespread, thick unit within the upper part of the Borrowdale Volcanic Group.

Elsewhere, a handful of old slate workings occurs in other formations from the upper part of the Borrowdale Volcanic Group: these have been omitted from the resource map. Mapping of the eastern part of the Borrowdale Volcanic Group outcrop by the BGS is nearing completion. A substantial resource of slate is probably present in this area, though its extent cannot be defined at present. A number of significant disused slate workings occur in an east-north-east-trending belt from Troutbeck to Kentmere, Wren Gill and Mosedale, near Shap. These rocks are largely within an eastward continuation of the Seathwaite Fell Formation.

Slate has been worked extensively from intensely cleaved mudstone and siltstone formations within the lower part of the Windermere Supergroup. Quarries, only two of which are working at present, occur in the Ashgill, Brathay and Wray Castle formations. Cleaved mudstones in the Latrigg Formation also comprise a resource. The Ashgill Formation is less than 30 m thick and has too narrow an outcrop to be shown on the resource map.

The blue-grey slate is mainly used for roofing. A regular, even cleavage is required; and thus the best quality slate is found where the cleavage is perpendicular to bedding. The ideal localities are within the cores of folds such as the Lowick and Stewnor anticlines. However, closely spaced joints may also be present there, making some of these zones unsuitable.

The largest slate operation is at Kirkby Quarry, which exploits a zone of silty mudstone extending for 750 m along strike and up to 50 m wide from the Wray Castle Formation on the north-west flank of the Lowick Anticline. There are still large reserves of slate in a zone extending downwards to near sea level; the base of the formation beneath the quarry area probably lies about 200 m below sea level (Johnson et al., 2000).

Several other rock units in the Lake District have had the epithet ‘slate’ attached to them, though they are not of the required quality to be included here as a resource. The ‘Skiddaw Slates’ (now known as the Skiddaw Group) have several sets of closely spaced fracture orientations, but none consistent enough to produce a suitable slate product. The Bannisdale Formation (formerly the Bannisdale Slates), in the upper part of the Windermere Supergroup, comprises strongly cleaved siltstone and mudstone. Locally, some parts of this unit may be suitable as slate, but no substantial workings are known.

CLAY AND SHALE

Clay and shale are used mainly in the manufacture of structural clay products, such as facing and engineering bricks, pavers, clay tiles and vitrified clay drainage pipes. In Britain, brick manufacture accounts for the largest tonnage use. Clays may also be used in cement manufacture, as a source of constructional fill and for lining and sealing landfill sites. The suitability of a clay for the manufacture of structural clay products depends principally on its behaviour during shaping, drying and, most importantly, firing. This behaviour will dictate the final properties of the fired brick, including its strength, porosity (water absorption), durability and aesthetic qualities.

Small brickworks mainly producing 'common' bricks from locally won raw materials were formerly a common feature in many industrial areas of Britain. However, in the last two or three decades there has been a major rationalisation of the brick industry which is now based on a small number of plants operated by a limited number of companies. With the decline of the 'common' brick, the main products are now high-quality facing bricks, engineering bricks and related products such as clay pavers. Modern brickmaking technology requires a high capital investment and is increasingly dependent, therefore, on raw materials with predictable and consistent firing characteristics in order to achieve high yields of saleable products. Blending different clays to achieve improved durability and to provide a range of fired colours and aesthetic qualities is an increasingly common feature of the brick industry. Continuity of supply of consistent raw materials is of paramount importance.

Clay bricks are produced at only one small plant in Cumbria, at Askham-in-Furness. A range of red facing bricks, engineering bricks, common bricks and pavers are manufactured by pressing and by the soft-mud process (formed in sand-lined moulds). The clays used are weathered mudstones from the Ordovician Skiddaw Group, which are extracted from a nearby quarry at High Greenscoe.

Fireclays

Fireclays are non-marine sedimentary mudstones and occur as seatearths, the fossils soils on which coal-forming vegetation once grew, which underlie most coal seams. Resources are, therefore, mainly confined to coal-bearing strata. They consist of comparatively thin (usually <1.0 m), unbedded mudstones with rootlets. The term 'fireclay' is used to describe seatearths which are of economic interest and they are generally named after the overlying coal (Highley, 1982).

Originally fireclays were valued as refractory raw materials, because of their relatively high alumina and low alkali contents. Demand for

fireclay for refractory use has, however, declined markedly since the late 1950s. This is mainly due to changing technology in the iron and steel industry where more severe operating conditions now demand much higher quality refractories. Only very small quantities of fireclay are now used for refractory applications. However, some fireclays may have relatively low iron contents compared with other brickmaking clays and they are now valued for the production of buff-coloured facing bricks and pavers. They are often blended with red-firing brick clays to give a range of fired colours.

Fireclays exhibit a wide range of mineralogical compositions and properties, both in terms of their vitrification characteristics and fired colour, the latter being largely a function of iron content. They consist essentially of the clay minerals kaolinite and hydrous mica, together with fine-grained quartz in varying proportions. Typically these three minerals make up some 90 per cent of the rock. Seatearths include all grades of sediment from mudstone (seatclay) to sandstone (ganister). Ganisters, or high silica sandstones, are comparatively rare, although they were formerly locally worked for refractory applications. Clay-rich seatearths, (seatclays), are much more common. Seatearths may exhibit rapid vertical and lateral variations in composition and thus properties. All are contaminated to a greater or lesser extent by impurities which render part, or the whole, of a seam unusable. Siderite, present as both clay ironstone nodules of variable size and sphaerosiderite less than 1 mm in diameter, and carbonaceous matter, present as coaly matter and fossil debris, are common constituents. They may represent serious impurities in commercial fireclays and restrict their use. Pyrite, which is often associated with carbonaceous material, may also be present as an impurity. In addition to carbon and sulphur, which should normally be less than 1.5 per cent and 0.1 per cent respectively, fired colour is the main criterion on which the suitability of a fireclay is judged for facing brick manufacture. Iron oxide contents should normally be less than 2.5–3.0 per cent Fe_2O_3 and on firing the fireclay should give a uniform buff/cream colour. However, depending on how the iron occurs, higher iron contents may be tolerated. The majority of seatearths are unsuitable for use, and fireclay production is localised both geographically and geologically.

The close association of fireclay and coal means that opencast coal sites provide one of the few viable sources of fireclay from which they are derived as a by-product. Fireclay resources are thus essentially coincident with shallow coal resources. However, only a small proportion of opencast coal sites normally produce fireclay. This may be due to the variable quality of the fireclays, or may be the result of operational or planning restrictions. However, the size and speed of opencast mining invariably creates a mismatch between potential supply and immediate market demand. Unless marketable fireclays can be stockpiled, either on or off site, they are usually backfilled with overburden and irrecoverably lost.

Small quantities of fireclay have been produced from opencast sites in the West Cumbrian Coalfield but the area has the disadvantage of being remote from major brickworks.

PEAT

Peat is an unconsolidated deposit of plant remains in a water saturated environment, such as a bog or fen, and of persistently high moisture content. There are two fundamental types of peatland in Britain; fens and bogs.

Fens occur in waterlogged locations where they receive nutrient in water from the surrounding catchment as well as rainfall.

Bogs occur in areas where they are largely dependent on rainfall for supply of water. Bog vegetation is characterised by acid tolerant plant communities in which the genus *Sphagnum* is the dominant component. There are two main types of acid bog peatlands in Britain. Raised bogs are characteristic of flat underlying topography and so are found mainly on low plains or broad valley floors. Blanket bogs occur in areas which are sufficiently cool and wet to allow the accumulation of peat on all but the steepest slopes. They occur in upland areas. A number of lowland raised bogs have been designated as sites of international and national conservation importance.

Amateur and professional gardeners use some 98 per cent of the peat extracted in Britain as a growing medium. Commercial peat extraction is based on raised bogs and there are extensive planning permissions for peat extraction in northern Cumbria. The largest workings are at Solway Moss, (343 ha with planning permission) Wedholme Flow (321 ha with permission) and Bolton Fell, (193 ha with planning permission). The latter two sites are SSSIs and part of Wedholme Flow has SAC status as an active raised bog.

HYDROCARBONS

Oil and gas within Great Britain and her territorial waters are in the ownership of the Crown and the Government grants licences to explore for and exploit these resources. The Department of Trade and Industry administers this licensing system. For landward exploration a Petroleum Exploration and Development Licence (PEDL) is required, which grants exclusive rights to exploit for and develop oil and gas onshore within GB. The rights granted by landward licences do not include any rights of access, and the licensees must also obtain any consent under current legislation, including planning permissions. Licensees wishing to enter or drill through coal seams for coalbed methane or coal mine gas must also seek the permission of the Coal Authority. PEDLs have been issued for parts of West Cumbria.

Coalbed Methane

Methane is one of the main by-products of the natural process of coalification, which is the low-grade metamorphism of peat through lignite to coal and anthracite. Some of this methane migrates from the source rock as it is formed but some remains either adsorbed onto internal free surfaces in the coal or is held as free gas within the natural fracture system in the coal bed. Through this process theoretical stored methane contents can be up to 34 m^3/t in anthracitic coal, although in Britain this value appears to peak at about 18 m^3/t. The economic recovery of coalbed methane involves entering the coal by boreholes, then fracturing and depressurising the coal seam to facilitate desorption and degassing of the methane.

The West Cumbrian Coalfield has been heavily worked, particularly along the coastal plain between Whitehaven and Maryport. The most recent deep mining was offshore beneath the Irish Sea, as the best seams were largely exhausted onshore. All deep mines in the area are now closed. In areas where coal has been worked the methane content of adjacent seams is likely to have been reduced. Longwall mining or the collapse of older mine workings has a de-stressing and depressurising effect on surrounding strata in a zone as much as 50 m below and 150 m above the worked seam. Lowering the pressure in a coal seam has the effect of allowing methane to desorb from it, lowering its coalbed methane prospectivity.

The methane content of the Main Band seam near Whitehaven is 7.5 m^3/tonne (Creedy 1986). This is high enough for coalbed methane extraction, other factors being favourable. The permeability of coal seams in the West Cumbrian Coalfield may be better than in many British coalfields. Creedy (1994) cites Solway Colliery as one of two areas in Britain where significant gas flows could be obtained from virgin coal seams.

Coal Measures rocks occur around the north-western, northern and north-eastern flanks of the Lake District and in the Canonbie district, straddling the Cumbria/Scotland border. Total coal thickness in the Lower and Middle Coal Measures (Westphalian A and B) succession in the central part of the West Cumbrian Coalfield (Area A on the inset map) was originally up to 28 m. The Main Band (the thickest seam) was up to 4.5 m thick in the Whitehaven area. Thus, in parts of this area there was originally an excellent resource base for coalbed methane, although this has been greatly reduced by subsequent mining. A detailed study of mine plans would be required to ascertain whether any good prospects remain.

On the northern margin of the coalfield (Area B on the map) the Main Band splits and becomes progressively less important eastward, as does the Ten Quarters, and the Yard Band becomes the thickest seam. Other seams have been worked irregularly but were

too thin to justify widespread mining. The Yard Band in this area was worked at the Oughterside, Brayton and Allhallows collieries and here there is not likely to be enough coal left to justify coalbed methane exploration.

To the east and north-east of the Lake District, (Area C on the map) mainly red, non-productive Coal Measures rocks occur at outcrop. Speculatively, productive Coal Measures could occur beneath these strata, but by analogy with Area B, they are unlikely to have good coalbed methane prospects.

Seismic interpretation suggests that Coal Measures rocks may occur at depth beneath the Solway area (Area D on the map), joining the concealed part of the Canonbie Coalfield in the north of the county with the concealed northern margin of the West Cumbrian Coalfield. This is unproved, but if Coal Measures are present, they could have coalbed methane potential.

The concealed extension of the Canonbie Coalfield (Area E on the map) is described by Picken (1988). It contains an average of around 16 m of coal and is untouched by mining. Average methane content is 6.3 m^3/t (Creedy 1991) and values reach at least 7.2 m^3/t. Prospects here are good if sufficient permeability exists. The Coal Measures may be steeply dipping near the eastern margin of the area due to the proximity of the Hilltop Fault.

Again, speculatively productive Coal Measures could be present beneath the Vale of Eden (Area F on the map), concealed by Permo-Triassic strata or reddened Coal Measures rocks. If so, they might have some coalbed methane potential.

With respect to permeability, gas content and total coal thickness, the coalbed methane prospects of parts of the West Cumbrian Coalfield are amongst the best in England. However, areas of virgin strata in which there are thick coals that have not been degassed by former mining need to be proved. If such areas can be found, then prospects are good. Prospects appear good in the concealed extension of the Canonbie Coalfield, but no information on coal seam permeability is available.

East of the Vale of Eden, a small part of the Midgeholme outlier of Coal Measures falls within Cumbria. This is not considered prospective for coal bed methane because the coal seams are too shallow and have been extensively mined.

The Little Limestone Coal (Namurian age) occurs both east and west of the Vale of Eden. Little is known about its gas content, but in Cumbria it is generally too shallow to form a coalbed methane prospect.

Coal seams also occur in the Lower Carboniferous (Dinantian) succession in the Solway Basin. Little is known about the regional thickness, continuity and gas content of these coals and thus they cannot be described as a coalbed methane prospect at the present.

Coal mine gas

The artificial voids left in abandoned coal mines form excellent potential reservoirs with high levels of permeability. They provide opportunities for extracting coal mine gas (containing methane) for electricity generation. Former mined areas of Coal Measures will have some potential.

Conventional Oil and Gas

Northern Cumbria

The conventional hydrocarbon potential of northern Cumbria (north of the Lake District) is summarised by Chadwick et al. (1995). This account summarises their findings. The northern part of Cumbria covers the western part of a major Carboniferous sedimentary basin, the Northumberland/Solway Basin. This contains a thickness of more than 4 km of Carboniferous strata in its deepest part, immediately north of the Maryport and Bank End faults.

Total organic carbon measurements on samples from a number of boreholes in the Northumberland/Solway Basin reveal levels in excess of 1 per cent and in several cases more than 5 per cent. Organic geochemical studies show that this organic matter is dominantly gas prone. Scattered occurrences of sapropelic oil-prone algal-rich rocks are known from boreholes and outcrop but their extent and volume is not known. Thus, the region has gas generating potential but oil generating potential is not proved.

With increasing temperatures and pressures organic matter in rocks is transformed into oil and gas (maturation). There is a steady increase in organic maturity with depth in the Northumberland/Solway Basin, except where the succession has been intruded by the Whin Sill. Much of the succession there is in the oil window. However, there is strong evidence that present day levels of organic maturity are about the same as achieved towards the end of the Carboniferous period, and that the peak period of hydrocarbon generation was in late Westphalian times. Much of any oil or gas generated at that time could have been lost as a result of deformation associated with the Variscan orogeny at end-Carboniferous times. Much of this evidence comes from the eastern (Northumberland) end of the basin.

Namurian and Westphalian (Upper Carboniferous) sandstones have sufficient porosity and permeability to act as hydrocarbon reservoirs in the East Midlands. In Cumbria they could have similar

characteristics. However, the Westnewton 1 well shows that there are few Namurian sandstones, and Westphalian sandstones are commonly exposed at the surface and/or heavily explored as a result of mining.

The Fell Sandstone and Middle Border Group are dominated by sandstones, which have excellent reservoir properties near outcrop. However, the Easton 1 well proved that they have poor reservoir properties at depth. Thus there is a lack of proved reservoir rocks in the region.

Potential oil and gas-bearing structures have been identified using seismic surveys. Three wells; Easton 1, Silloth 1 and Westnewton 1, have been drilled to test the hydrocarbon potential of these Cumbrian parts of the Northumberland/Solway Basin. All these wells were plugged and abandoned as dry holes. Minor gas shows were recorded from the Lower Border Group (Dinantian) in Easton 1.

The gas-prone organic matter and generally poor reservoir characteristics suggest that the prospects for finding economic hydrocarbons in northern Cumbria are not encouraging. Nonetheless, it is considered that there is likely to be sporadic exploration in the area in the future.

Southern Cumbria

An exploration well, Biggar 1, has been drilled on Walney Island, near Barrow-in-Furness. The potential source rocks in this area are Namurian mudstones, which source the oil and gas fields in the East Irish Sea Basin. The Triassic Sherwood Sandstone Group forms the reservoir in these fields. Biggar 1 tested the Sherwood Sandstone, but was unsuccessful.

The inset map on the Mineral Resources Map shows the location and results of oil and gas exploration wells in Cumbria.

GYPSUM / ANHYDRITE

Gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$) are the naturally-occurring forms of calcium sulphate which normally occur as beds or nodular masses up to a few metres thick. They are considered together because they are genetically associated. Calcium sulphate is precipitated through the progressive evaporation of seawater. Gypsum is formed by the hydration of anhydrite at or near surface, but passes into anhydrite generally at depths of more than about 100 m. Anhydrite is, therefore, very much more extensive than gypsum and Britain's anhydrite resources are extremely large. Gypsum is highly soluble and dissolves rapidly at or near the surface. Irregular solution of gypsum beds can lead to the development of cave systems which may present a hazard both to

surface stability and in mining. The presence of solution cavities near surface may be unpredictable.

In Cumbria several gypsum/anhydrite beds occur within mudstones of late Permian age in the Vale of Eden, near Whitehaven in west Cumbria, and in south Cumbria. Several beds have been worked, both for gypsum and anhydrite, and formed the basis of a large mining industry in the past. Mining of anhydrite is now on a very much reduced scale, but the Vale of Eden remains one of the major centres of gypsum production in Britain. Mining is now confined to the Kirkby Thore area.

Anhydrite, when pure, contains 23.5 per cent sulphur and is the only naturally-occurring form of the element to have been worked on any scale in Britain. However, anhydrite is no longer of economic importance as a source of sulphur. Gypsum is used principally in the manufacture of plaster and plasterboard. A mixture of gypsum/anhydrite is also used as a retarder in the manufacture of cement. Anhydrite also has a few specialist applications.

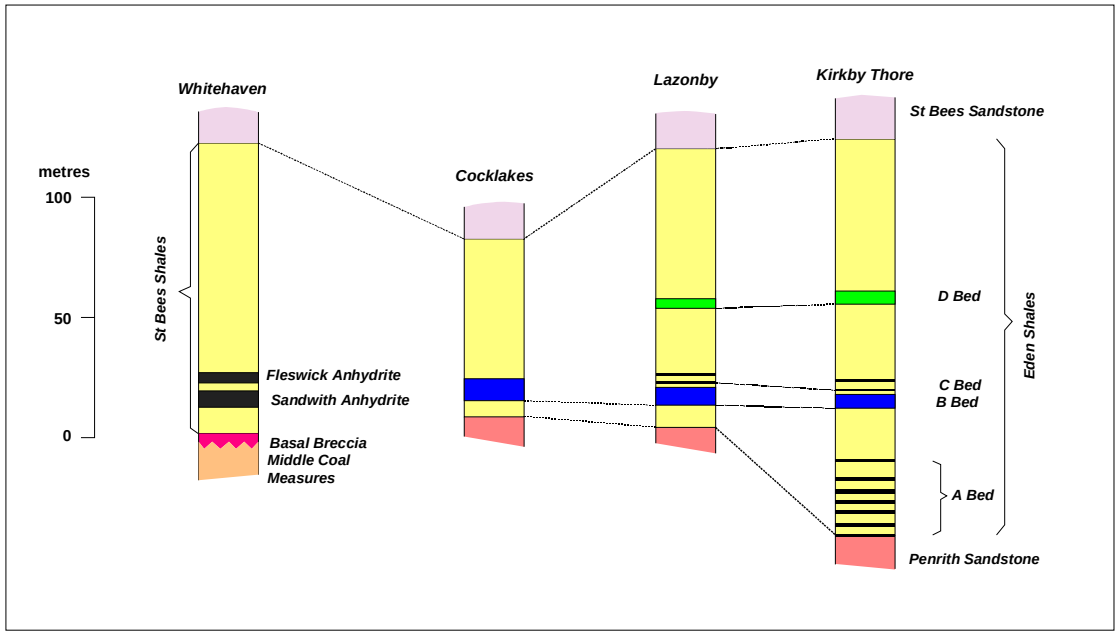


Figure 5. Generalised section of Permian rocks, showing the occurrence of gypsum/anhydrite (after Meyer, 1965).

In the Vale of Eden several beds of anhydrite occur within the Eden Shales, the four thickest being referred to in ascending order by the letters A to D (see Figure 5). At outcrop and beneath shallow overburden (up to some 100 m) calcium sulphate occurs as gypsum but anhydrite is extensive at depth. The lowest gypsum, A bed, at the base of the Eden Shales is laterally impersistent and largely confined to the Kirkby Thore area. It consists of interbedded mudstone, siltstone and gypsum/anhydrite up to some 30 m thick,

although only about 9 m are worked. Reserves of A bed are large but its low gypsum content imposes certain limitations on its use. In contrast, the B bed is up to 6.5 m thick and is widespread throughout all but the southernmost part of the Vale. It extends at least into the southern part of the Carlisle Basin, around Cocklakes, where it was formerly worked, initially by quarrying and later by mining. The succeeding, but thinner, C bed is almost as extensive, and the D bed, up to 3 m thick, is also present throughout most of the Vale. The C and D beds are unworked

Gypsum has been extracted mainly by mining, although some quarrying has taken place. Anhydrite has only been produced by mining. The A bed is currently extracted for gypsum at the Birkshead Mine in the Kirkby Thore area and was formerly worked at the nearby Longriggs Mine, which is now closed. The B bed is worked at the Newbiggin Mine as a source of anhydrite for cement manufacture and specialist applications. The mine was opened in 1964. The B bed was also formerly mined at the Long Meg Mine near Lazonby. The mine was opened in 1895 for gypsum but was developed on a large scale after 1954 for the supply of anhydrite for the manufacture of sulphuric acid at Widnes. The mine closed with the cessation of sulphuric acid manufacture at Widnes in 1973. Gypsum was also produced during this period. Gypsum production in the Vale of Eden is now on a reduced scale because of the availability of desulphogypsum from the Drax coal-fired power station in Yorkshire. However, the availability of desulphogypsum in the longer term is not assured.

Permian strata crop out locally along the coastal strip in the Whitehaven area and gypsum and, particularly anhydrite, occurs within an evaporite succession at the base of the St Bees Shales (See Figure 5). Gypsum was worked underground at the Barrowmouth Mine at Saltom Bay, south of Whitehaven, but increasing proportions of anhydrite in the bed led to the mine's closure in 1908. Anhydrite was mined on a large scale at the Sandwith Mine beneath St Bees Head and offshore for use locally in the manufacture of sulphuric acid, cement being an important by-product. The mine started production in 1955 and produced some 8 million tonnes of anhydrite up to its closure in 1975. The anhydrite averaged about 92 per cent $CaSO_4$ and was worked from two beds, each some 4.5 m thick, separated by 3 m of dolomitic limestone. Mining ceased because the economics of producing sulphuric acid from anhydrite became increasingly unattractive in the face of cheap and plentiful supplies of imported crude sulphur.

A similar evaporite succession is present at the base of the St Bees Shales in south Cumbria, but no workings for either gypsum or anhydrite have taken place. The evidence suggests that anhydrite is the dominant mineral present in the succession and thus the area would not appear to be very prospective for gypsum. The St Bees

Shales crop out in a discontinuous belt at the base of the St Bees Sandstone between Aspatria and Gaitsgill and in the Brampton and Hethersgill areas, although no gypsum/anhydrite of commercial interest has been reported. Thin beds of gypsum/anhydrite have been identified in the St Bees Shales of the Riddings area in the north of the county where some exploration has taken place.

Gypsum/anhydrite may occur in the upper parts of the Triassic Mercia Mudstone Group of the Carlisle Basin at levels comparable to those worked in Staffordshire and the East Midlands. However, no information is available.

As commercial quantities of gypsum/anhydrite only occur within the Eden Shales–St Bees Shales only this formation is shown on the resource map. In the Vale of Eden the inferred outcrop of one or more of the evaporite beds have been shown where data are available. Anhydrite is highly unlikely to be of economic importance as a large scale source of sulphur in the foreseeable future. It is anticipated, therefore, that future interest will be directed principally at gypsum and thus on beds that are close to outcrop.

HALITE

Halite ('rock salt', NaCl) occurs interbedded with mudstone at three main levels in the Triassic Mercia Mudstone Group on Walney Island and beneath the Walney Channel and parts of western Barrow-in-Furness.

The highest unit occurs in the Kirkham Mudstone Formation and comprises a representative of the Preesall Salt of west Lancashire (Wilson, 1990). This halite has a well-defined base but its upper surface is subject to solution and is a 'wet rock-head' zone in which the evaporite is overlain by collapsed and brecciated mudstones representing overlying beds in the Mercia Mudstone Group. The thickness of the Preesall Salt varies according to its depth from the surface and the extent of solution in the 'wet rock-head' zone. The maximum thickness proved (c. 116 m) was recorded in the Walney Island No. 5 borehole, North Scale, where halite was encountered at 110.64 m depth. There, the lowest 39.46 m is dominated by halite, including one 21.32 m-thick unit. Mudstone interbeds are scarce in this part of the Preesall Salt but are more common in the overlying c.76m in which halite forms one 8.38 m-thick unit and is dominant in some units up to 16.61 m thick, but mudstone dominates others up to 16.62 m thick. Thinner Preesall Salt successions were proved below wet rock-head in the Walney Island No. 2 and 3 boreholes at Biggar. Brine from this halite supported a small-scale salt industry earlier this century.

Smaller amounts of halite occur in the underlying Singleton Mudstone Formation, with concentrations at two levels which

correspond to the Rossall and Mythop salts of west Lancashire. These units were proved on Walney Island, in the BG 1 borehole near Biggar. The lower (Rossall) unit is 16 m thick and includes 14 m of halite in three beds which range from 3–7 m in thickness and are separated by thin mudstones. About 31 m of mudstone with two thin beds of halite separate this unit from the higher (Mythop) unit in which halite occurs principally in the lower 33 m and the upper 19 m of a 102 m-thick succession. The lower development includes 22 m of halite in five beds which range from 1 to 13 m in thickness and are separated by mudstone from 1–5 m thick. The upper development includes 14.45 m of bedded halite and halite in a mudstone matrix in three beds, separated by mudstones. In the BG 1 borehole the top of the Mythop Salt is at 228.70 m and that of the Rossall Salt is at 362 m.

The Walney Island salt deposits are continuous with the more extensive deposits offshore in the East Irish Sea, together with those formerly worked in west Lancashire, at Preesall. However, they are highly unlikely to be of economic interest in the future, either as a source of salt or for the development of storage cavities, because of the presence of wet rock-head and the fact that individual halite beds are thin.

A six metre-thick halite unit was encountered at about 167 m depth, some 200 m above the base of the Mercia Mudstone Group in the Silloth 1A borehole, on the south side of the Solway Firth. This unit is thought to correspond with the Preesall Salt of west Lancashire; its extent within the Solway Firth Basin is unknown.

IRON ORES

One of the county's major mineral products, and the basis for the heavy industry of west and south Cumbria, was hematite (Fe_2O_3). Large deposits of this iron ore were worked in the area between Lamplugh and Calder Bridge (the West Cumbrian Orefield) and in the Millom and Furness areas (the South Cumbrian Orefield). Very much smaller quantities were raised from related deposits in the Lake District, mainly in the Ennerdale and Eskdale areas.

The earliest records of hematite mining in Cumbria date from the 12th century and mining is known to have been active in the 17th and 18th centuries. Large-scale exploration and mining during the 19th century culminated in the peak years for production. Throughout the first half of the last century both the west and south Cumbrian orefields continued to supply substantial tonnages of ore to the steelworks at Barrow, Millom and Workington. Progressive exhaustion of the largest orebodies, failure to locate large new reserves, changes in steelmaking technology and a variety of economic difficulties brought about a severe decline in the fortunes of the Cumbrian iron ore mining and smelting industry in the second

half of the 20th century. This led to the closure of the last south Cumbrian mine, Hodbarrow at Millom, in 1968 and the closure of the combined Florence-Beckermet Mine at Egremont in 1980. A small-scale revival of mining at this latter mine, shortly after the closure of large-scale working, continues today. It has been estimated that a total of around 250 million tonnes of hematite have been mined from Cumbria. Current output from Florence Mine, recorded as 1 200 tonnes in 1999, is used as a pigment and for foundry purposes.

Hematite orebodies in west and south Cumbria occur as large, irregular or flat-lying replacements of Carboniferous limestones. The distribution of orebodies exhibits a number of clear structural and stratigraphical controls. Most are closely associated with faults and hematite replacement mineralisation, although present in most of the limestone units, displays a marked preference for certain limestones. In west Cumbria the Seventh, Fourth and First limestones were preferentially replaced; in south Cumbria mineralisation is concentrated within the Red Hill Oolite and to a rather lesser extent the Urswick Limestone. In addition to these orebodies, the Furness area of south Cumbria contains numerous hematite bodies known as 'sops'. In these deposits, which are unique to Furness, hematite fills large, roughly conical dissolution hollows in the limestone, with the centre of each sop typically filled with sand. The Lower Palaeozoic rocks of the Lake District locally host fissure veins of hematite. These are especially numerous in the Skiddaw Group rocks of the Kelton Fell area and the granitic intrusions of Eskdale and Ennerdale. All of these deposits are composed almost exclusively of hematite in a variety of forms. Compact massive hematite is most abundant but the county is well known for the fibrous mammillated variety known as 'kidney ore'. Very small quantities of manganese ores have been mined from a few deposits and some copper ore was recovered from one hematite mine in Furness. A restricted range of gangue minerals, including dolomite, quartz, calcite, baryte and fluorite, comprises a very small proportion of the orebodies. The ore typically graded about 50 per cent Fe, with 10 per cent SiO_2, and 2 per cent CaO with very low levels of P (0.02 per cent) and S (0.05 per cent).

The origin of the Cumbrian hematite deposits has long been the subject of discussion and controversy. A variety of genetic models have been developed and these have played a crucial role in exploration for new deposits. The most generally accepted models today both involve the transport of iron in solution by brines expelled from the East Irish Sea Basin, though different sources of iron are proposed. Rose and Dunham (1977) suggested the leaching of iron from Permo-Triassic sediments whereas Shepherd and Goldring (1993) favour the Lake District granites as the source. Both models are consistent with the iron-rich mineralising fluids gaining access to the host rocks of the deposits via fractures as well

as through permeable formations within the overlying Permo-Triassic sequence. Young (in Jones et al., 1990) has speculated that certain Coal Measures sandstones may have acted as mineralising aquifers in suitable structural settings. If so, as yet undiscovered orebodies could be present at depth within limestones to the west and south of the known West Cumbrian Orefield. However it is highly unlikely that there will be any interest in these deposits in the foreseeable future

Useful descriptive accounts of the hematite orefields, together with summaries of genetic models are contained in Smith (1924) and Akhurst et al. (1997).

Very much smaller quantities of iron ore have been worked from clay ironstone nodules within the Coal Measures of west Cumbria. Some siderite and 'limonite' ores associated with the vein deposits of the Alston area have also yielded small tonnages. None of these deposits are now of economic significance and are unlikely to attract future interest.

NON-FERROUS METALLIFEROUS MINERALS

Historically, two of Britain's foremost metalliferous mining areas, the Lake District and North Pennines, fall entirely or partly within the area. However, apart from a small amount of high-grade hematite for pigments, no metals are now produced. Most mining for base-metals took place in the 19th century, tailing off rapidly after about 1880. All the non-ferrous mines exploited vein-style deposits with locally important replacement-style mineralisation in Carboniferous limestone adjacent to veins in the North Pennines. All the known metalliferous deposits are now either exhausted or are uneconomic to work under current conditions. The veins in the Lake District contain a wide variety of minerals resulting in production of copper, lead, zinc, tungsten and smaller amounts of antimony, arsenic, cobalt, manganese and nickel (Stanley and Vaughan, 1982; Millwood et al, 2000). For a short period, sulphur in the form of pyrite was extracted from at least one site for use in sulphuric acid manufacture. Large amounts of barytes and small amounts of quartz have also been produced from the veins (Eastwood, 1921; Smith, 1923; Dewey & Eastwood, 1925; Adams, 1988).

In the North Pennines the veins contain a smaller range of minerals, dominated locally by one or more of galena, sphalerite, baryte, fluorite, witherite and iron carbonates with calcite and quartz. Small amounts of copper are also present locally but most production has been for lead and zinc ores and non-metallic gangue minerals such as baryte, fluorite and witherite.

The last operating metalliferous mines in the Lake District were Carrock Fell, worked intermittently for tungsten until 1981, and Force Crag which was worked for lead, zinc or barytes until 1966; attempts at re-opening the mine and minor production of zinc and barytes continued until 1991. In the North Pennines most metallic mineral production had finished by 1920. The production of non-metallic mineral, with minor amounts of lead and zinc ores as by products, continued into the 1990s on a declining trend from one or more mines to the east of the county boundary. In recent years modest quantities of barytes have been produced from a mineral vein and associated replacement deposits at Silverband near Appleby. Remaining known reserves are small.

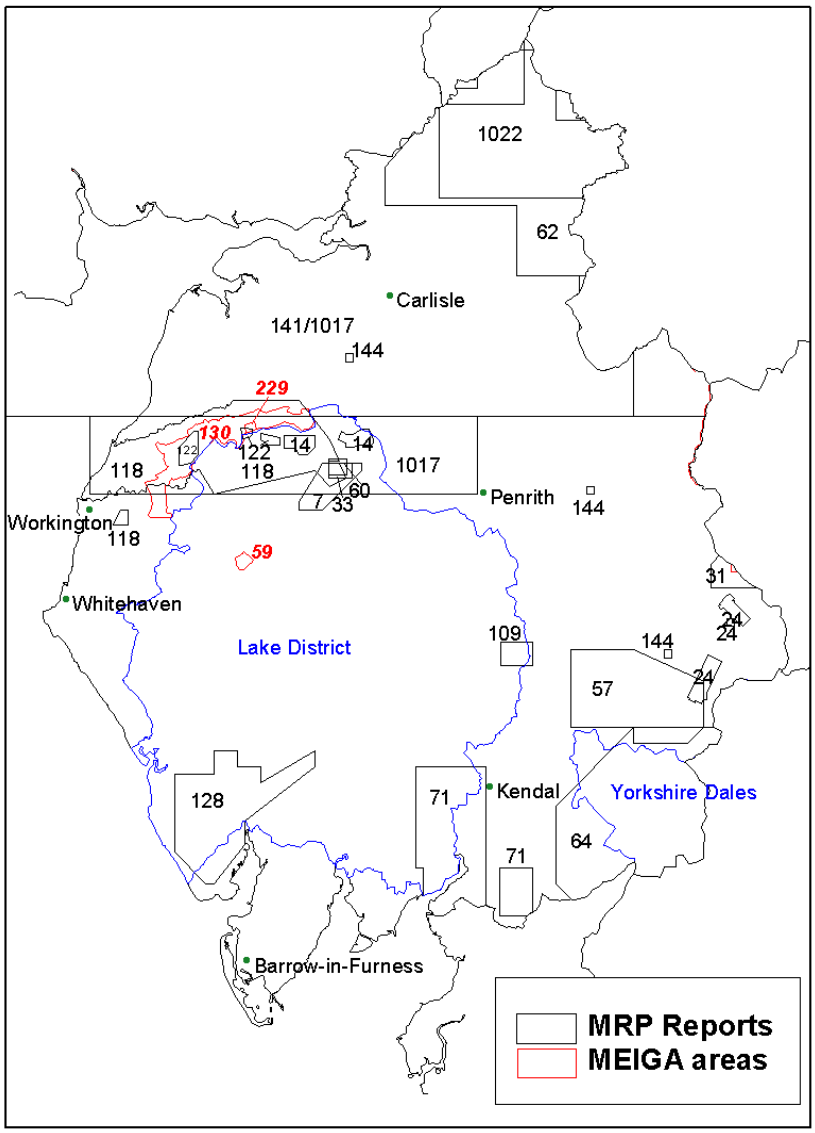


Figure 6. MRP and MEIGA report areas in Cumbria

Exploration

Between 1972 and 1995 the BGS carried out a number of exploration projects in Cumbria under the Mineral Reconnaissance Programme (MRP), funded by the Department of Trade and Industry. Projects were aimed at finding new evidence for the existence of mineral deposits that could be developed by the private sector. Other projects were undertaken by companies utilising the provisions of the Mineral Exploration and Investments Grants Act 1972 (MEIGA). Under the conditions of the Act, reports on work carried out under it are now on open file: copies are held by the BGS. MRP and MEIGA reports are listed in the bibliography. Exploration work has been concentrated on rocks of Lower Carboniferous age peripheral to the Lake District National Park or close to the eastern county boundary.

Most exploration work was aimed at finding 'Irish-style' base-metal mineralisation in the Lower Carboniferous rocks (MRP reports 14, 24, 31, 57, 62, 64, 71, 118, 122, MEIGA reports 130, 229). Some evidence of mineralisation was found locally and it is likely, depending in part on commodity prices, that further investigations of the Lower Carboniferous for this type of deposit will be undertaken from time to time. A regional overview of the prospectivity of northern England for carbonate-hosted base-metal deposits is given in Plant and Jones (1999).

The possible presence of baryte and base-metal mineralisation along the margins of the Northumberland/Solway Trough was considered by Young et al. (1992). Other work investigated tungsten mineralisation associated with the Skiddaw Granite (MRP reports 7, 33 and 60). One report (109) describes the search for copper-molybdenum mineralisation associated with the Shap Granite and MEIGA work (report 59) investigated remaining Pb-Zn-Ba reserves in the vein-style mineralisation formerly exploited at Force Crag Mine. Currently, it seems unlikely that these will be pursued further except from an academic viewpoint.

A basic intrusion at Carrock Fell contains appreciable quantities of apatite, ilmenite and magnetite which locally may comprise up to 25 per cent of the rock. The intrusion has been suggested as a possible ilmenite (titanium) resource, but no detailed evaluation has been undertaken.

The last MRP report produced on work in Cumbria (No. 128) described mineralisation in the Black Combe area, close to the southern margin of the Lake District National Park. New evidence for gold and tungsten mineralisation was reported.

SECONDARY AGGREGATES

The term 'secondary aggregates' is used to describe a range of materials which may be used as alternatives to primary aggregates (subject to considerations of quality and contamination), but which arise as wastes from a variety of activities. These may be considered under three main headings:

- Naturally-occurring materials arising from mineral extraction and processing operations, such as slate waste, colliery spoil, overburden and quarry/processing waste
- Materials arising from industrial processes, such as iron and steel slags and power station ash, which may be of variable composition
- Construction and demolition wastes, which may be either in a natural or manufactured state and include asphalt planings, road sub-base, concrete rubble and masonry. These materials are excluded from this study as their arisings are highly variable in location, type and duration.

Utilising the aggregate potential of such materials may have the advantage of both reducing the demand for primary aggregates and thus land for mineral extraction, and the problems of disposing of waste. In general, however, secondary aggregates are only suitable for less demanding aggregate applications, and their production and use may not always be environmentally or economically desirable. There are only limited resources of secondary aggregates in Cumbria, but these include the slag banks at former iron and steel plants in Millom, Workington and Barrow, the latter two of which are still worked.

Slate waste

The production of roofing slate has in the past created large amounts of waste, both processing waste and also material which is unsuitable for splitting (Richards, Moorehead and Laing Ltd, 1995). This waste material is usually tipped adjacent to the working area. Crushed and graded slate can be used for construction applications, such as Type 1 and Type 2 sub-base, large blocks can be used for armour stone, smaller blocks for rip rap, and for drainage blankets, pipe trench backfill, french drain fill and capping and blinding layers. It also provides a source of bulk fill for construction projects, including road embankments. However, the low price of the material and high transportation costs usually restricts its use to the vicinity of production.

Slate waste tips are associated with all the slate operations, the most extensive being those in the Kirkby in Furness area.

Other materials

Colliery spoil is the waste from mining and processing coal. It consists mainly of mudstone and siltstone. In Cumbria, former tips have largely been reclaimed/restored and are not now available as a source of secondary aggregate.

Iron ore waste tips have been worked for aggregate, and are mostly restored. Some large tips remain.

Small waste tips from former base metal mining operations occur in a number of areas but the waste is largely unsuitable for use as secondary aggregate because of its variable composition and the presence of sulphides, which present a potential pollution risk if disturbed.

There are no coal-fired power stations in the area and, therefore, no supplies of pulverised fuel ash or furnace bottom ash.

MINERAL RESOURCES AND PLANNING CONSTRAINTS

Mineral extraction can cause irrevocable, but not necessarily harmful, change to a locality over a relatively short timescale. In order to ensure that such changes are sustainable and do not harm the environment the most valuable landscapes, National Parks and AONBs, are given the highest level of protection from development. The need for mineral working in such areas has to be justified by a most rigorous examination of the merits of the proposal. This examination considers the wider public interest in the development of the resource and the social and economic issues as well as the need to protect the environment.

A hierarchy of national and international nature conservation designations is also used to protect areas of habitat interest. Mineral proposals within, or likely to affect Sites of Special Scientific Interest (SSSI) should be subject to rigorous examination. Mineral extraction in areas designated as Special Protection Areas (SPAs) or Special Areas of Conservation (SACs) may be acceptable if there are no alternatives and if there are imperative reasons of overriding public interest. For certain priority SACs, development can only be considered to be acceptable if there are overriding reasons of public health or safety or due to beneficial environmental consequences. Whilst the requirement to assess the acceptability of mineral working in such designated areas is therefore stringent, there is no total prohibition on working minerals in such areas.

The resolution of conflicts between mineral resource development and other considerations is undertaken through the development plan framework and the development control system with a balanced appraisal of the issues raised. The three Mineral Resource Maps of Cumbria provide syntheses of available information which can be revised and updated as additional data becomes available. Additional constraint information can be incorporated as required. It is hoped that these maps and the associated report will assist local and national government, the minerals industry and other interests in the consideration and production of policies in development plans.

The landscape character of Cumbria and the Lake District reflects the nature and structure of the underlying rocks, the erosive forces to which they have been subjected and the soil and vegetation that they support. This character is constantly changing due to economic and social pressures in the short-term and to geomorphological processes in the long-term.

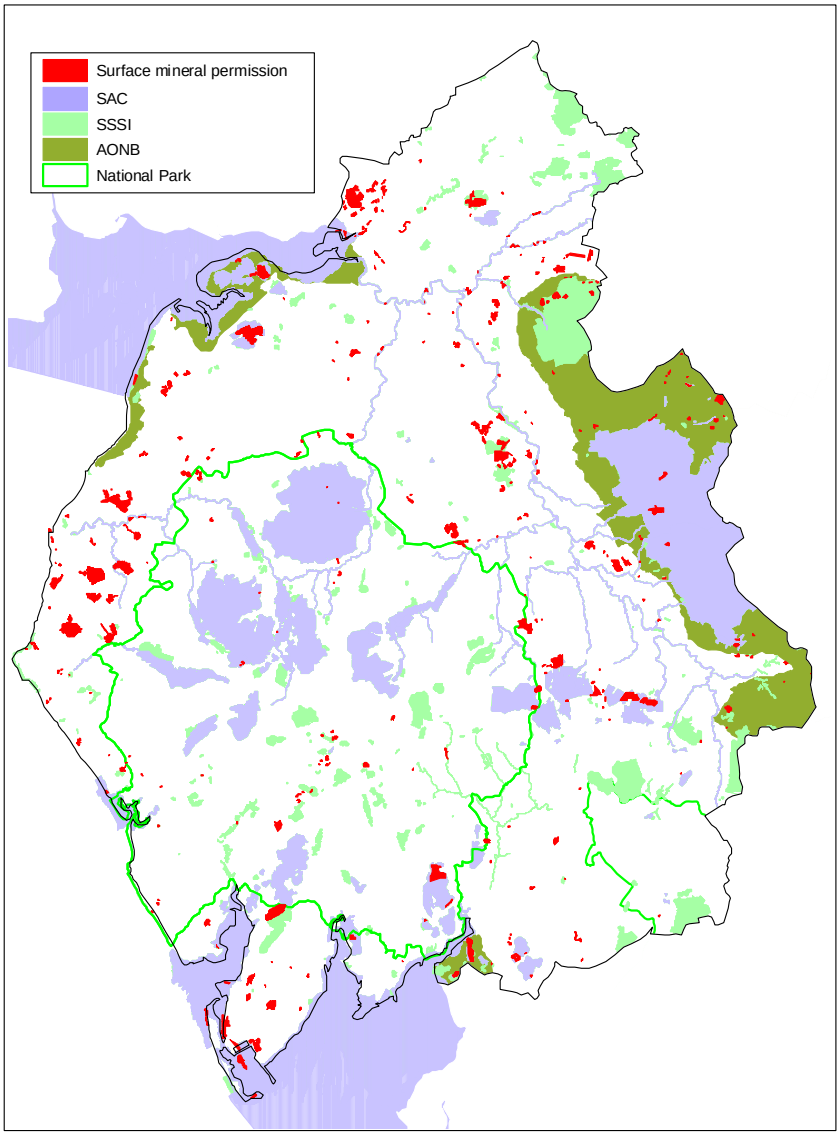


Figure 7. Principal environmental designations in Cumbria and surface mineral planning permissions, for NNR see maps.

The extent of the principal environmental designations and their relationship to mineral planning permissions is shown in Figure 7. The area of Lake District, the estuary of the Solway, Morecambe Bay and the north-western flank of the Pennines have long been considered areas of great landscape value and/or nature conservation importance. A large percentage of Cumbria is, therefore, designated as AONB, National Park and SSSI, (including NNR, SAC and SPA). Areas designated include the central lakes, the rivers Derwent and Eden and their tributaries and all of the Pennine escarpment east of the Vale of Eden. These latter impact on the sand and gravel resources of the county which are largely confined to the river valleys. In addition, the semi-coastal AONBs of the Solway Coast and Arnside & Silverdale cover some of the productive peat

resources, and some of the southern limestone resource, both of which contain operational workings.

Within the National Parks, there are no active workings in the Yorkshire Dales National Park in Cumbria, but the Lake District National Park supports a thriving slate industry. The larger quarries fall outside the border of the National Park. Slate workings are important as a source of local stone for both new construction and restoration of older buildings.

Opencast coal resources are little affected by designations, as much of the outcrop in the Cumbria coastal area is urbanised and/or has been industrialised in the past, and hence of less landscape value. In the Pennines, however, the limestone, igneous rock and coal resources all fall within the North Pennines AONB, which also includes some large SSSIs, SACs s and SPAs. Most of the large-scale operations for vein minerals have either now ceased or were underground. Currently, limestone quarries at Hartley and Helbeck, the small Silverband barytes operation, one small drift coal mine, and some small building stone operations are working within the AONB.

In the Vale of Eden and the western and Furness outcrops of the Carboniferous Limestone, there are several large workings. The gypsum/anhydrite workings are largely underground, but large limestone quarries are working on or near the National Park boundary. Several large SACs on limestone outcrop overlie large permissions for the collection of limestone pavement. Small, but important building stone workings in the Penrith Sandstone are partly covered by SSSIs, e.g. on Lazonby Fell.

Local landscape and conservation designations made by local authorities are not shown on the accompanying maps, however these will be found on the relevant local plans. These include areas of high landscape value, which lie outside the nationally designated areas.

Other local and site-specific factors may affect mineral operations. These factors represent technical constraints rather than fundamental policy constraints and can only be considered on a site by site basis. They are excluded from the maps.

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For further information on national planning policy, users should consult the following:

- Planning Policy Guidance
- Mineral Planning Guidance Notes
- Regional Planning Guidance Notes

published by the HMSO for the Department of the Environment, Transport and the Regions.

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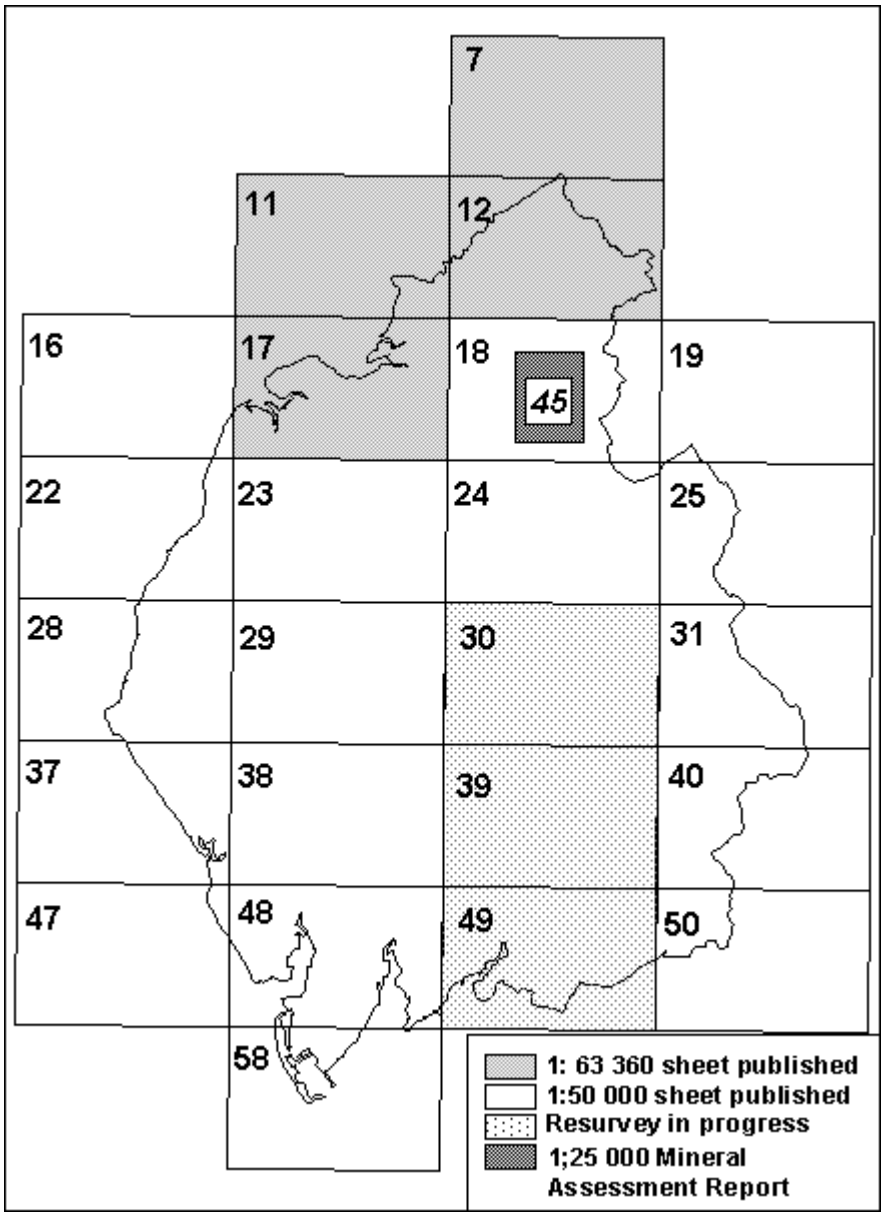

Figure 8. Availability of British Geological Survey 1:25 000, 1:50 000 and 1:63 360 scale geological map coverage. For up to date availability of digital map coverage see www.thebgs.co.uk or www.british-geological-survey.co.uk.

a) British Geological Survey 1:50 000 and 1:63 360 geological map sheets

Sheet	Name	Edition	Published
7	Kielder Castle	S + D	1950
7	Kielder Castle	SwD	1950
11	Longtown	S + D	1925
12	Bewcastle	S + D	1969
12	Bewcastle	SwD	1969
16	Silloth	D	1925
17	Carlisle	S + D	1925
18	Brampton	S	1976
18	Brampton	S + D	1980
19	Hexham	S	1975
22	Maryport	S, S + D	1995
23	Cockermouth	S	1997
23	Cockermouth	S + D	1997
24	Penrith	S + D	1974
24	Penrith	SwD	1974
25	Alston	SwD	1973
28	Whitehaven	S	1976
28	Whitehaven	S + D	1976
29	Keswick	S	1999
29	Keswick	S + D	1998
31	Brough under Stainmore	S + D	1974
31	Brough under Stainmore	SwD	1974
37	Gosforth	S	1999
37	Gosforth	S + D	1998
38	Ambleside	S	1996
38	Ambleside	S + D	1998
40	Kirkby Stephen	S + D [P]	1997
40	Kirkby Stephen	SwD	1972
47	Bootle	S, S + D	1997
48	Ulverston	S + D	1997
50	Hawes	S + D [P]	1997
58	Barrow in Furness	S, D	1976
30, 39, 49	Resurvey in progress		
	S Solid edition D Drift edition S+D Solid and Drift combined SwD as above with uncoloured drift sheet	P – Provisional edition	

b) British Geological Survey Sheet Memoirs

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Ref. No.	Project name	Target Elements	Company
59	Force Crag	Cu Pb Zn	Force Crag Mines
130	Torpenhow	Cu	Consolidated Goldfields
229	Bothel	Cu Pb Zn	BP Minerals PLC

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APPENDIX 1: Mineral workings in Cumbria and the Lake District (2000)

Name of Working	Operator	Commodity
Newbiggin Mine	British Gypsum Ltd	Anhydrite
Silverband Openpit	Waiting Minerals Ltd	Barytes
Derwent Howe Slag Bank	Solway Aggregates Ltd	Blast Furnace Slag
Clarghyll Colliery	W Thompson & K Carrick	Coal, Deep
Keekle Head	Cumberland Coal Company	Coal, Opencast
High Greenscoe	Furness Brick & Tile Co Ltd	Common Clay & Shale
Birkshead Mine	British Gypsum Ltd	Gypsum
Ghyll Scaur	Aggregate Industries Northern	Igneous & Metamorphic
Florence Mine	Egremont Mining Co Ltd	Iron Ore - Hematite
Baycliff Haggs	Hodgestone	Limestone
Bothel (Moota)	RMC Aggregates (Northern) Ltd	Limestone
Eskett & Rowrah Quarries	Aggregate Industries Northern	Limestone
Hartley	RMC Aggregates (North West) Ltd	Limestone
Helbeck	Sherburn Stone Co Ltd	Limestone
Holme Park (Clawthorpe)	Aggregate Industries Northern	Limestone
Middlebarrow (Silverdale)	Hanson Aggregates - North	Limestone
Parkhead	Hanson Aggregates - North	Limestone
Pickering (Orton Scar)	Cumbria Stone Quarries Ltd	Limestone
Rooks	Cumbria Stone Quarries Ltd	Limestone
Sandside	Tarmac Central Ltd	Limestone
Shapfell Limestone (Hardendale)	Corus Plc	Limestone
Silvertop	W & M Thompson (Quarries) Ltd	Limestone
Stainton	Tarmac Northern Ltd	Limestone
Tendley	Tendley Quarries Ltd	Limestone
Bolton Fell	William Sinclair Horticulture Ltd	Peat
Boothby	William Sinclair Horticulture Ltd	Peat
Kirkbride Moor	The Scotts Company (UK) Ltd	Peat
Solway Moss	Richardson's Moss Litter Co. Ltd (HUMAX)	Peat
Wedholme Flow	The Scotts Company (UK) Ltd	Peat
Aldoth Quarry	D A Harrison	Sand & Gravel
Bonnie Mount	J E A & S M Burne	Sand & Gravel
Brocklewath	W Roper	Sand & Gravel
Bullgill Sand Pit	Thomas Armstrong Ltd	Sand & Gravel
Cardewmires	Tarmac Northern Ltd	Sand & Gravel
Faugh No 1 Sand Pit	Hanson Aggregates - North	Sand & Gravel

Name of Working	Operator	Commodity
Highfield	D A Harrison	Sand & Gravel
Holmrook (Peel Place)	Peel Place Sand & Gravel	Sand & Gravel
Kirkhouse	Lakeland Minerals Ltd	Sand & Gravel
Knock Parish Quarry	Long Marton Parish Council	Sand & Gravel
Low Gelt Farm Sand Pit	Hanson Aggregates - North	Sand & Gravel
Low Plains	Tarmac Northern Ltd	Sand & Gravel
New Cowper & Aikshaw	Thomas Armstrong Ltd	Sand & Gravel
Overby No 2 Sand Pit	Thomas Armstrong Ltd	Sand & Gravel
Peel Place (Holmrook)	Peel Place Sand & Gravel	Sand & Gravel
Roose Sand Pit (Roosecote)	Tarmac Northern Ltd	Sand & Gravel
South Walney (South End)	Tarmac Northern Ltd	Sand & Gravel
Bankend	Natural Stone Products	Sandstone
Birkhams (St Bees)	Cumbria Stone Quarries Ltd	Sandstone
Bowscar Quarry	Norwest Quarries Ltd	Sandstone
Brackenbank	Balderstone Quarries	Sandstone
Brownrigg Fell (West Brownrigg)	Cumbria Stone Quarries Ltd	Sandstone
Crag Nook (Stoneraise)	Block Stone Ltd	Sandstone
Flinty Fell	Hodgson Brothers	Sandstone
Grange Quarry	E Moorhouse & Sons	Sandstone
Holmescales	Aggregate Industries Northern	Sandstone
Lamb Hill	J & M Casson	Sandstone
Leipsic	Northern Paving & Landscape	Sandstone
Mousegill Bridge	Mr K Buckle	Sandstone
Roan Edge	RMC Aggregates (North West) Ltd	Sandstone
Scratchmill Scar (Lazonby Fell)	Cumbria Stone Quarries Ltd	Sandstone
Kirkby Slate (Burlington)	Burlington Slate Ltd	Slate
Partly in Cumbria, partly in National Park		
Shap Beck	Hanson Aggregates - North	Limestone
Shap Blue Quarry & Works	RMC Aggregates (North West) Ltd	Igneous & Metamorphic
Kendal Fell	Tarmac Northern Ltd	Limestone
Lake District National Park		
Shap Pink	RMC Aggregates (North West) Ltd	Igneous & Metamorphic
Brathay	Kirkstone Green Slate Quarries	Slate
Broughton Moor	Burlington Slate Ltd	Slate
Bursting Stone (Coniston)	Burlington Slate Ltd	Slate
Elterwater	Burlington Slate Ltd	Slate
High Fell (High Tilberthwaite)	High Fell Greenslate Co Ltd	Slate
Hodge Close	Hodge Close Green Slate Quarry	Slate

Name of Working	Operator	Commodity
Honister Mine	Honister Slate Mine	Slate
Low Brandy Crag	Burlington Slate Ltd	Slate
Petts	Kirkstone Green Slate Quarries Ltd	Slate

APPENDIX 2: Contact addresses for further enquiries

Cumbria County Council Development Control Division County Offices Kendal Cumbria LA9 4RQ Tel: 01539 773000 Fax: 01539 773439 Webpage: www.cumbria.gov.uk	Lake District National Park Authority National Park Office Murley Moss, Oxenholme Road Kendal Cumbria LA9 7RL Tel: 01539 724555 Fax: 01539 740822 Webpage: www.lake-district.gov.uk
Allerdale Borough Council Allerdale House Workington Cumbria CA14 3YJ Tel: 01900 326333 Fax: 01900 326506 Webpage: irisi.works.co.uk/GRAPHICS/CSITES/allerdal	Barrow Borough Council Town Hall Barrow-in-Furness Cumbria LA14 2LD Tel: 01229 894900 Fax: 01229 894217 Webpage: www.barrowbc.gov.uk
Carlisle City Council Civic Centre Carlisle Cumbria CA3 8QG Tel: 01228 817000 Fax: 01228 817199 Webpage: www.historic-carlisle.org.uk	Copeland Borough Council Catherine Street Whitehaven Cumbria CA28 7NY Tel: 01946 852585 Fax: 01946 852790 Webpage: www.copelandbc.gov.uk
Eden District Council Mansion House Penrith Cumbria CA11 7YG Tel: 01768 864671 Fax: 01768 890732 Webpage: www.eden.gov.uk	South Lakeland District Council South Lakeland House Lowther Street Kendal LA9 4UG Tel: 01539 733333 Fax: 01539 740300 Webpage: ourworld.compuservecomhomepages/sldc/
Countryside Agency John Dower House Crescent Place Cheltenham Gloucestershire GL50 3RA Tel: 01242 521381 Fax: 01242 584270 Webpage: www.countryside.gov.uk	Yorkshire Dales National Park Yorebridge House, Bainbridge Leyburn North Yorkshire DL8 3EE Tel: 01969 650456 Fax: 01969 650 386 Webpage: www.yorkshiredales.org.uk
English Nature Northminster House Northminster Peterborough PE1 1UA Tel: 01733 455000 Fax: 01733 455103 Webpage: www.english-nature.org.uk	The Coal Authority 200 Lichfield Lane Mansfield Nottinghamshire NG18 4RG Tel: 01623 427162 Fax: 01623 638338

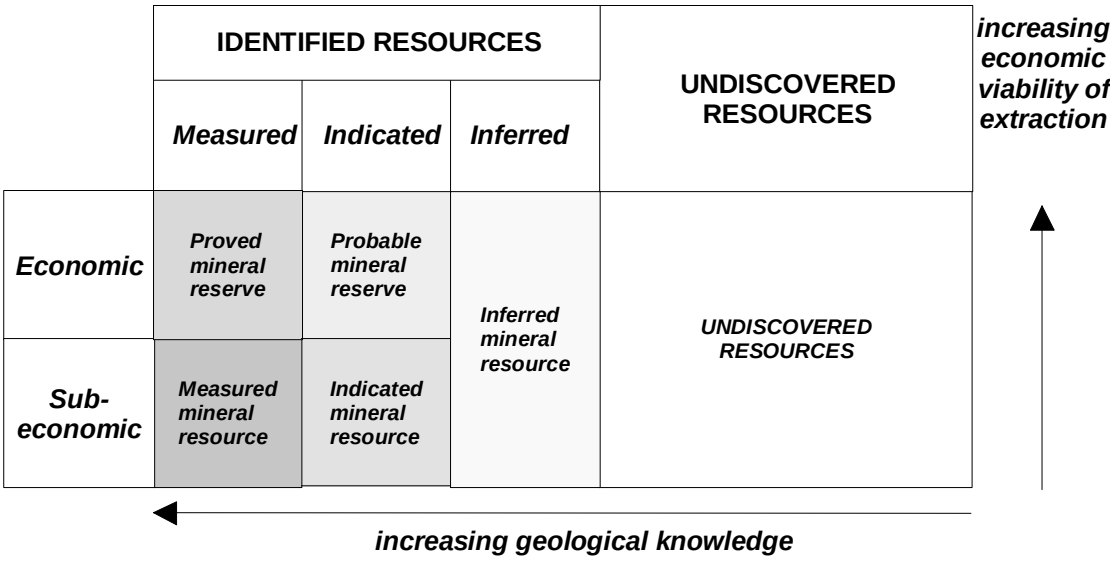
English Heritage Fortress House Savile Row London SW1X 1AB Tel: 0207 973 3000 Fax: 0207 973 3001 Webpage: www.english-heritage.org.uk	The Environment Agency Northern Area Office (North West Region) Ghyll Mount, Gillian Way Junction 40 Business Park Penrith Cumbria CA11 9BP Tel: 01768 866666 Fax: 01768 865606
The Secretary Northern Regional Aggregate Working Party Northumberland County Council Planning and Environment Division County Hall Morpeth NE61 2EF Tel: 01670 533000 Fax: 01670 534069	The Secretary North West Regional Aggregate Working Party Cheshire County Council Environment Planning Service Commerce House Hunter Street Chester CH1 2QP Tel: 01244 603181 Fax: 01244 603033

APPENDIX 3: Methodology

The British Geological Survey (BGS) was commissioned in 1993 by the Department of the Environment to prepare, on a trial basis, a set of concise statements mainly in map form, to show the broad distribution of mineral resources in selected counties and to relate these to selected, nationally-designated planning constraints. The trial study developed a methodology for the collection and display of data in a consistent and comparable format for four Mineral Planning Authority (MPA) areas - Bedfordshire, Derbyshire, Staffordshire and the Peak District National Park. The concept developed by the BGS for the trial study is now being extended to some twenty mineral planning authorities in England and Wales through a further phase of the project which started in 1996.

The main element of the trial study was the production of maps, with accompanying interpretative reports, for each MPA area. All mineral resource and planning constraint information has been collated digitally on a PC-based system using Intergraph Microstation to produce a cartographic database. Data has been captured as a series of files, structured on separate levels so that they can be viewed either independently or in various combinations, as required. Most of the information has been taken digitally from hard copy maps, mainly with scales between 1:50 000 and 1:10 000. Other material was obtained in a variety of digital formats which have had to be converted for use by the Intergraph Microstation System. The structure of the information will allow the data to be transferred in digital form to the BGS MINGOL (MINerals GIS On-Line) system. MINGOL is being developed to provide a decision-support system for the rapid solution of minerals-related problems to aid corporate and public mineral resource management. It applies a state-of-the art GIS to relate the nature and distribution of mineral resources to other information such as planning and environmental constraints, and mineral exploration, borehole and commodity statistics datasets.

Figure 1. Classification of resources and reserves



Based on McKelvey, 1972

As the data are held digitally, map output can be on any scale but 1:100 000 has been found to be a convenient size to summarise the information for individual MPAs. This provides a legible topographic base which enables both the broad implications of the information, and sufficiently accurate detail, to be shown. The particular advantage of holding all the information in digital form is that it is comparatively easy to update and revise as additional information becomes available, and also provides scope for producing customised maps of selected information or areas on request.

Classification of reserves and resources

The diagram, Figure 1, is a representation of a conventional method for classifying mineral reserves and resources, based on a system introduced the US Bureau of Mines and the US Geological Survey and adapted by the British Geological Survey. In this conceptual diagram the vertical dimension of the diagram represents the economic viability of the resource and consists simply of two categories, **economic** and **sub-economic**, depending on whether or not the mineral deposit is commercially viable under prevailing economic circumstances. As demand, mineral prices and costs of extraction may change with time, so mineral resources may become reserves and vice versa.

The horizontal dimension represents degrees of geological knowledge about the resource, from mere speculation about its existence (right-hand side) to thorough assessment and sampling on a systematic basis (left-hand side).

In the present study the mineral resource information has been produced by the collation and interpretation of data principally held by the British Geological Survey. Since the mineral resource data presented are not comprehensive and the quality is variable, the boundaries shown are approximate. Most of the mineral resource information presented is, therefore, in the **inferred resource** category (Figure 1), that is to say, those resources that can be defined from available geological information and which may have some economic potential. They have neither been evaluated by drilling, or other sampling methods, nor had their technical properties characterised on any systematic basis. Inferred resources may be converted into indicated and measured resources with increasing degrees of investigation and assessment. However, where mineral resource studies (including drilling and testing) have been carried out, sufficient information is available to define the resource at the **indicated** level. Sand and gravel assessment studies have been carried out in parts of Cumbria.

A mineral resource is not confirmed as economic until it is proved by a relatively expensive evaluation programme. This usually involves a detailed measurement of the material available for extraction together with an evaluation of the quality of the material, its market suitability, the revenues generated by its sale and, ultimately, the viability of the deposit. This activity is an essential precursor to submitting a planning application for mineral extraction. That part of a resource that is both ‘measured’ and ‘economic’, i.e. that has been fully evaluated and is commercially viable to work, is called a **reserve** or **mineral reserve**. It is customary to distinguish **proved** and **probable reserves**, which correspond to the economic parts of measured and indicated resources respectively (Figure 1).

It is invariably the case that there is a significant reduction in area or volume estimates as resources are further investigated to prove reserves. The reasons for this is that it is impossible to apply initially all the various constraints that working procedures and environmental issues may impose. This is particularly the case with extensive deposits like sand and gravel where physical constraints imposed by roads, railways and urban development may drastically reduce the potential area available for extraction, even before factors such as quality and mineral thickness are taken into consideration.

In the context of land-use planning the term **reserve** should strictly be further limited to those minerals for which a valid planning permission for extraction exists, i.e. **permitted reserves**. The extent of mineral planning permissions (other than coal) is shown on the Mineral Resources Maps. These cover both active mineral workings and inactive mineral workings. Some mineral planning permissions may have remained unworked, and others may have become uneconomic prior to being worked out. In many cases the areas involved are likely to have been worked to some extent in the past, and may now be restored. In addition, parts of the resource areas may have been fully evaluated by the minerals industry, but either have not been subject to a planning application or have been refused permission for extraction. These areas are not depicted on the map.

A **landbank** is a stock of planning permissions and is commonly quoted for aggregates. It is composed of the sum of all **permitted reserves** at active and inactive sites at a given point of time, and for a given area, with the following provisos:

- it includes the estimated quantity of reserves with valid planning permission at dormant or currently non-working sites;
- it includes all reserves with valid planning permission irrespective of the size of the reserves and production capacity of particular sites;
- it does not include estimated quantities of material allocated in development plans but not having the benefit of planning permission; and
- it does not include any estimate for the contribution that could be made by marine dredged, imported or secondary materials.

It is important to recognise, however, that some of the permitted reserves contained within landbanks have not been fully evaluated with the degree of precision normally associated with the strict use of the term reserves, indeed some may not have been evaluated at all.

Mineral workings and planning permissions

The locations and names of mineral workings in Cumbria and the Lake District are shown on the maps. The information is derived from the British Geological Survey's Mines and Quarries Database, updated as appropriate from Cumbria County Council, The Lake District National Park Authority or The Yorkshire Dales National Park Authority's records. Letters (e.g. **Sg** = sand and gravel) are used to show the main mineral commodity produced.

The extent of the planning permissions shown on the Mineral Resources Map cover active mineral workings, former mineral workings and, occasionally, unworked deposits. The present physical and legal status of the planning permissions is not qualified on the map. The areas shown may, therefore, include inactive sites, where the permission has expired due to the terms of the permission, i.e. a time limit, and inactive (dormant) sites where the permission still exists. Sites which have been restored are not separately identified. Under the provisions of the 1995 Environment Act, after 1 November 1997, sites that are classified as dormant may no longer be worked until full modern planning conditions have been approved by the Mineral Planning Authority. A 'dormant site' is defined as a site where no mineral development has taken place to any substantial extent in the period 23 February 1982 and ending 6 June 1995. Information on the precise status and extent of individual planning permissions should be sought from Cumbria County Council, The Lake District National Park Authority or The Yorkshire Dales National Park Authority.

Most planning permissions appear on a mapped mineral resource area and thus the underlying resource colour identifies the mineral type. Planning permissions may fall outside resource areas for the following reasons:

- permissions shown partly off resource areas may extend to ownership, or other easily defined boundaries, or to include ground for ancillary facilities such as processing plants, roads and overburden tipping

- isolated workings occurring outside defined resource areas may reflect very local or specific situations, such as a borrow pit, not applicable to the full extent of the underlying rock type:

The latest data available for the total areas of planning permissions in Cumbria, collected for the Department of Environment Minerals Survey of 1994, is shown in Table 1. This information is updated at intervals.

Table 1. Areas of planning permissions for mineral workings in Cumbria and the Lake District (as at 1.4.94)

		Commodity	Total permitted area (ha)	No. of sites	%
Cumbria					
Surface workings		Clay/shale	10	2	0.33
		Coal (opencast)	668	5	21.74
		Gypsum/anhydrite	78	1	2.54
		Igneous rock	20	2	0.65
		Limestone/dolomite	755	23	24.58
		Peat	847	3	27.57
		Sand and gravel (construction)	288	21	9.38
		Sandstone	61	15	1.99
		Slate	280	1	9.11
		Vein minerals	24	1	0.78
		Other minerals	41	2	1.33
	Total		**3072**	**76**	**100**
Underground workings		Coal (specific planning perm.)	376	2	17.74
		Coal (under GDO)	241	1	11.37
		Gypsum/anhydrite	1410	1	66.54
		Ironstone	92	1	4.34
	Total		**2119**	**5**	**100**
Lake District					
Surface workings		Clay/shale	1	1	0.28
		Igneous rock	83	4	23.58
		Limestone/dolomite	203	4	57.67
		Sand and gravel (construction)	4	1	1.14
		Slate	61	9	17.33
	Total		**352**	**19**	**100**
Underground workings		Vein minerals	89	2	100
	Total		**89**	**2**	**100**

Source: *Department of the Environment, 1996. Survey of Land for Mineral Workings in England, 1994.*