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

Devon (comprising Devon, Plymouth, Torbay, Dartmoor National Park and part of Exmoor National Park)

Commissioned Report CR/05/096N

BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/05/096N

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

Devon (comprising Devon, Plymouth, Torbay, Dartmoor National Park and part of Exmoor National Park)

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This report accompanies the 1:100 000 scale maps: Devon, North and South (comprising Devon, Plymouth, Torbay, Dartmoor National Park and part of Exmoor National Park)

Key words

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Ball Clay extraction in the Bovey Basin, Devon. Photo by David Highley © BGS NERC 2006

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1 Introduction

This report is one of a series prepared by the British Geological Survey for various administrative areas in England for the Office of the Deputy Prime Minister's research project *Mineral Resource Information in Support of National, Regional and Local Planning.*

The accompanying maps relate to the county of Devon and delineates the mineral resources of current, or potential, economic interest in the area and the sites where minerals are or have been worked. It also relates these to national planning designations, which may represent constraints on the extraction of minerals.

Three major elements of information are presented:

- the geological distribution and importance of mineral resources;
- the extent of mineral planning permissions and the location of current mineral workings; and
- the extent of selected, nationally-designated planning constraints.

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 map on the scale of 1:100 000. This scale is convenient for the overall display of the data and allows for a legible topographic base on which to depict the information. However, all the data are held digitally at larger scales using a Geographical Information System (GIS), which allows easy revision, updating and customisation of the information together with its possible integration with other datasets. The information will form part of a *Summary of the Mineral Resources of the South West Region.*

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 discussion on specific planning proposals for minerals extraction or on proposals, which may sterilise resources.

It is anticipated that the map 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.

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 mineral resources covered are sand and gravel, crushed rock aggregate, brick clay, kaolin, ball clay, building stones, hydrocarbons and metalliferous mineralisation.

1.1 RESOURCES AND RESERVES

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 that make them suitable for specific uses and be present in sufficient quantity to be of intrinsic economic interest. Areas that are of potential economic interest as resources of minerals change with time as new uses are developed, product specifications change, recovery technology is improved or more competitive sources become available.

That part of a mineral resource, which has been fully evaluated and is commercially viable, to work is called a mineral reserve. In the context of land-use planning, 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 made non-viable by changing economic circumstances.

Mineral resources defined on the maps delineate areas within which potentially workable mineral may occur. These areas are not of uniform potential and also take no account of planning constraints that may limit their working. The economic potential of individual 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. Extensive areas are shown as having no mineral resource potential, but some isolated mineral workings may occur in these areas. The presence of these operations generally reflects local or specific situations.

1.2 ENVIRONMENTAL DESIGNATIONS

The map shows 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:

- National Parks – Dartmoor and Exmoor (part);
- Area of Outstanding Natural Beauty – North Devon, South Devon and parts of East Devon and Blackdown Hills;
- Heritage Coast;
- National nature conservation designations – National Nature Reserves (NNR) and Sites of Special Scientific Interest (SSSI)
- International nature designations – Special Areas of Conservation (SAC), Special Protection Areas (SPA) and Ramsar sites; and
- Scheduled Monuments.

Mineral development may also be constrained by many other factors not shown on the map, 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 Mineral Planning Authority.

2 Sand and gravel

Sand and gravel are defined on the basis of particle size rather than composition. In current commercial practice, following the introduction of new European standards from 1st January 2004, the term 'gravel' (or more correctly coarse aggregate) is used for general and concrete applications to define particles between 4 and 80 mm and the term 'sand' for material that is finer than 4 mm, but coarser than 0.063 mm. For use in asphalt 2 mm is now the break point between coarse and fine aggregate. Most commercial sand and gravel is composed of particles that are rich in silica (quartz, quartzite and flint), but other rock types may occur locally.

The principal uses of sand are as fine aggregate in concrete, mortar and asphalt. The main use of gravel is as coarse aggregate in concrete. Substantial amounts of sand and gravel may also be used as constructional fill.

Sales of land-won sand and gravel in Devon were reported (AMRI) to be some 1.3 million tonnes in 2004. Marine-dredged sand and gravel is landed in Plymouth and Appledore.

Two main categories of sand and gravel are defined:

- Superficial deposits include river terrace and sub-alluvial deposits
- Bedrock deposits: These are represented by the Triassic, Budleigh Salterton Pebble Beds, the Permian, Dawlish Sandstone Formation, the Eocene, Aller and Haldon Gravel formations, and Palaeogene sands of the Bovey Formation.

Available data on sand and gravel resources are relatively limited. Only exposed sand and gravel is defined. Narrow (<200 m) spreads of alluvial deposits are excluded from the map as their limited width is likely to preclude economic working. All alluvial deposits in the south and west of Devon are also excluded from the map since, as in neighbouring Cornwall, these are generally limited in extent and extremely unlikely to be of any economic interest.

2.1 SUPERFICIAL DEPOSITS

Superficial sand and gravel resources in Devon are of limited importance. River sand and gravel (alluvial) deposits are typically developed as alluvium and river terraces along the major river valleys (Rivers Axe, Exe, Taw and Torridge). There are many unworked river terrace deposits, such as those of the River Okement (up to 8 feet of gravel) and the thick deposits of the River Taw. The terrace deposits of the River Exe contain sandstone and vein quartz pebbles from the Culm measures and were recently worked at Hayes Farm Quarry at Clyst Honiton, east of Exeter. Sand and gravel extraction was formerly permitted in the Taw-Torridge estuary, where tidal deposits yielded a shelly mixed-graded material.

2.2 BEDROCK DEPOSITS

Bedrock deposits account for all the sand and gravel produced in Devon. The Budleigh Salterton Pebble Beds are of Triassic age and are the most important source of sand and gravel in the county. The pebble beds occur as a narrow strip of disconnected outcrops, with a well-defined west facing scarp (up to 25 m high) traceable north from Budleigh Salterton across East Devon and Somerset to the Bristol Channel coast. They consist mainly of medium brown rounded pebbles, cobbles and boulders of quartzite with a small proportion of sandstone, siltstone, mudstone and igneous rocks in a paler brown matrix of fine to coarse gravel and silty sand. They represent sediments deposited in braided rivers draining from the south/ southwest. They are

currently worked at several locations in Devon, including Blackhill Quarry near Woodbury and Hillhead Quarry near Uffculme. In the Blackhill area they are 30 m thick, and yield 105 000 to 125 000 tonnes of sand and gravel per acre. Typically, they contain 10% silt/clay, 50% sand and 40% gravel.

The late Permian, Dawlish Sandstone Formation is a reddish brown, weakly cemented sandstone which is quarried at Bishops Court near Exeter for use as a mortar sand.

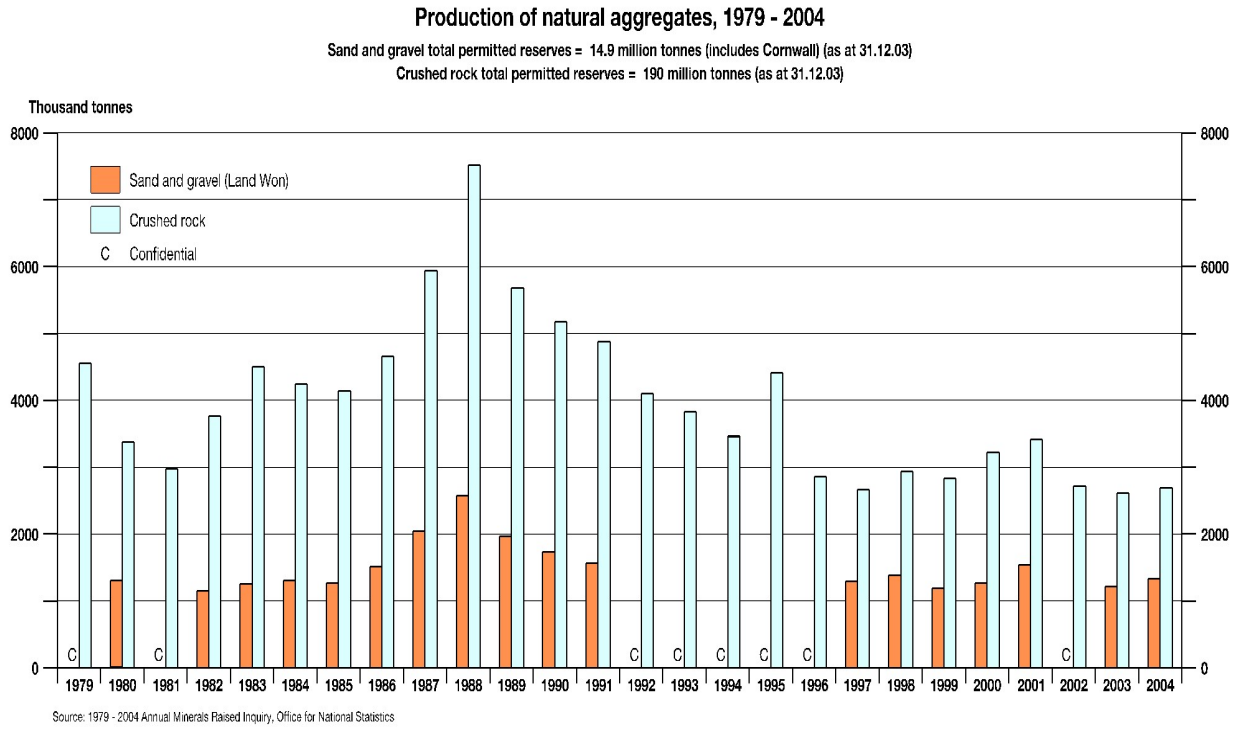

Figure 1. Production of sand and gravel and crushed rock aggregate in Devon, 1981-2004.

Note: sand and gravel figures include marine won resources, but marine sand and gravel generally makes up less than 10% of the total.

The Eocene Aller Gravel Formation is mainly composed of grey and brown flints, with sand and silty clay and has a restricted distribution near Newton Abbot. It is worked at Zig Zag Quarry, near Newton Abbot. The Eocene Haldon Gravel Formation is s sequence of flint-rich gravels, which is worked at Haldon Quarry.

The Cretaceous age Upper Greensand Formation, which occurs across east Devon as far west as Newton Abbot, is greenish coloured fine-grained sand. It ranges from 20 to 76 m in thickness. Historically, it was worked in east Devon as a foundry moulding sand. The sole site now, in part, working the Upper Greensand in Devon is at Babcombe Copse Quarry near Newton Abbot. The Upper Greensand is not shown on the map as its extensive outcrop is unlikely to be of economic interest because of its fine-grained nature.

The sand interburden to some of the ball clay seams in the Bovey Formation in the Bovey Basin is being worked for construction and industrial use.

3 Crushed rock aggregate

A variety of rocks are, when crushed, suitable for use as aggregates, either on their own or bound with cement to produce concrete and bitumen for asphalt. Their technical suitability for different aggregate applications depends on their physical characteristics, such as crushing strength, porosity and resistance to impact, abrasion and polishing. Higher quality aggregates are required for specific uses, such as road surfacing and for use in concrete. Lower quality aggregates may be acceptable for applications, such as constructional fill and drainage media. The main sources of crushed rock aggregate in Devon are limestone, igneous rock and sandstone.

3.1 LIMESTONE AND CHALK

Limestones are an important source of aggregate minerals in Devon. The main limestones of economic interest are:

- Middle to Upper Devonian (East Ogwell Limestone, Chercombe Bridge Limestone, Brixham Limestone Formation, Torquay Limestone Formation and Plymouth Limestone Formation);
- Lower Carboniferous (Bampton Limestone and Westleigh Limestone formations); and
- Upper Cretaceous (Chalk).

Devonian limestones occur across south Devon. The Plymouth Limestone Formation occurs to the southeast of Plymouth. It consists of dark-grey, massive fossiliferous limestones and is worked at Moorcroft Quarry. The East Ogwell Limestone occurs between Chudleigh and the Teign Estuary. It is pale to medium grey, poorly bedded and is worked at Stoneycombe Quarry. The Chercombe Bridge Limestone is a dark-grey, well-bedded limestone with interbedded shale. The Torquay Limestone Formation is a grey to pinkish-grey, massive or thick-bedded, fine-grained, limestone which is sometimes locally dolomitised.

Lower Carboniferous limestones occur in east Devon, close to the Somerset border. The Westleigh Limestones consist of well-bedded, fine- to medium-grained detrital limestones with some interbedded shales, chert and conglomerates. These are worked at Westleigh Quarry near Tiverton. This deposit consists of an elongate inlier surrounded by Permian mudstones and breccias. The Bampton Limestone comprises dark bioclastic limestones and shale with associated chert.

Chalk is worked in east Devon at Uplyme near Lyme Regis for use as constructional material and agricultural lime.

In the past, there have been numerous small-scale workings of thin limestones which occur within the shale sequences of the Lower Carboniferous (Pilton Shales). Limestones have also been worked in north Devon from strata of Devonian (Ilfracombe Slates) and Lower Carboniferous age (Codden Hill Chert Formation and Meldon Chert).

3.2 IGNEOUS ROCK

Dolerite is a basic igneous rock that, in Devon, occurs as dykes and sills intruded into Devonian and Carboniferous sequences and that has been subsequently been altered by low-grade regional metamorphism. Dolerites occurring within the thermal aureole of the Dartmoor Granite have been metamorphosed to metadolerite, which has improved their strength. The extent of the thermal aureole shown on the map. The properties of dolerite vary considerably locally and the outcrops may be of limited size; they are mostly less than 50 m thick, although they can locally reach 100 m in thickness.

Dolerite is an important source of roadstone aggregate within South West England. Quarrying of dolerite is generally more expensive than alternatives (such as limestone and sandstone) because the deposits are smaller and more irregular and they are more difficult to crush due to their hardness. Locally they have been affected by deep weathering and alteration.

The dolerite sill of Trusham Quarry, in the Teign Valley, is intruded into the Lower Carboniferous Combe Shale Formation. Currently, this quarry is being redeveloped to enable extraction of unweathered dolerite. The dolerite sill of Whitecleaves Quarry, near Buckfastleigh, is intruded into the grey mudstone sequence of the Devonian Saltash Formation. These dolerites are worked occasionally for concrete and roadstone. Aggregate from both quarries is sent to a plant at Trusham Quarry to produce coated roadstone. Metadolerite, together with associated metapelite (hornfels), from the Meldon Quarry is used as a general purpose aggregate.

3.3 SANDSTONE

The Devonian and Carboniferous formations which underlie much of Devon include substantial thicknesses of mudstone (slate and shale), siltstone and sandstone. These have all been affected by the Variscan earth movements, which produced complex folding and faulting and low-grade regional metamorphism. The sandstones vary considerably, both in grain-size and in quartz content, ranging from quartzites, with a high quartz content to greywackes (gritstones), with some original clay/silt content in addition to quartz and other mineral grains. In places, the greywackes have the geotechnical characteristics of low Aggregate Abrasion Value (AAV < 8) and high Polished Stone Value (PSV > 60), which makes them suitable for use as road surfacing material. In most cases, the individual sandstone beds occur together with beds of shale, slate or siltstone, and the feasibility of economic high-PSV sandstone production is dependent on the removal of the finer material, and/or the selection of those more sandstone-rich parts of the succession.

Considerable thicknesses of hard sandstone are present in the Early Devonian Staddon Grit Formation (Staddon Formation of recent authors), which crops out in south Devon. These are considered likely to include much high-PSV material, but are not worked at present. The Middle Devonian Hangman Grit Formation of north Devon is a similar case, as are the Late Devonian Pickwell Down Sandstone Formation and Baggy Sandstone Formation. The Late Devonian/Early Carboniferous Pilton Mudstone Formation contains thick developments of sandstone which are actively worked for road-surfacing materials. Typical PSV figures are in the range 59 – 61, and AAV figures in the range 5.0 – 7.0.

The Late Carboniferous Crackington Formation has a considerable area of outcrop in north, central and west Devon. Much of the formation is dominated by shale, with thin interbeds of turbidite sandstone, but in places there are substantial developments of sandstone, with individual beds exceeding one metre in thickness. These are actively worked for high-quality sandstone where it has proved possible to screen out much of the shale and/or siltstone content. The sandstones of the Crackington Formation show consistently high PSV figures across the whole area of outcrop, ranging from 58 – 66, with a mean of 62 from 8 measurements. AAVs are low, ranging from 3.2 to 7.6, with a mean of 4.8 from 8 measurements. The Bude Formation and Bideford Formation, also of Late Carboniferous age, crop out over large areas of west and central Devon. The Bude Formation includes some substantial developments of turbidite sandstones, with similar properties to those of the underlying Crackington Formation. These were formerly worked on a considerable scale for example in the Morchard Bishop area. However, the Bude and Bideford formations also include sequences of softer-weathering sandstone, which may have PSV figures up to 70, but have unacceptably high AAVs. The broad distribution of sandstone-bearing strata is shown on the inset map. Sandstone bodies will occur in these units but their potential for road-surfacing aggregate would require detailed assessment.

The Meldon Chert is a sequence of cherts, cherty siltstones and shales with quartz veining and lenses of black limestone of Lower Carboniferous age. It occurs in the Meldon area, south of Sourton to Sticklepath, within the thermal aureole of Dartmoor Granite. It is worked at Meldon Quarry near Okehampton. This quarry was formerly known for its production of railway ballast, which supplied much of South West England. This supply is now overtaken by granite brought in from Scotland.

4 Building stones

Currently there are ten quarries producing building stone in Devon; four in Devonian slate, five in Carboniferous sandstone, and one quarry in granite.

Historically, Devon has produced a very wide range of stones for building purposes. The oldest rocks of the area are metamorphic schists, slates, limestones, and sandstones of the Devonian. The schists of the Start Complex were locally worked for building stone at Salcombe. The slaty rocks of the succession were worked in the past, both for the roofing slate and as a local building stone across much of its outcrop.

The limestones of the Devonian (such as the Chercombe Bridge Limestone Formation) formerly supported an extensive 'marble' (polished limestone) industry, around Plymouth, Ashburton and Torquay. These rocks were also used in these areas as building stone. Thin sandstones occur throughout the Devonian and Carboniferous successions in the county. These have only been worked for local building purposes in the past and are rarely used beyond their local outcrop area. The hard, coarse-grained breccias of the Permian (such as the Heavitree Breccia Formations) also provided local building stone.

In the east of the county, the glauconitic sandstones of the Lower Cretaceous (Upper Greensand) were extensively quarried for building stone in the past, most notably for Exeter Cathedral. Around Blackborough, in east Devon the same succession contains chert nodules which have been used locally for building purposes, as well as supporting a large whetstone (batts) industry in the past.

The Upper Cretaceous (Turonian) hard, chalky, shelly limestones from Beer on the east Devon coast have been mined and quarried since medieval times for building stone (known locally as 'Beer Stone'). This stone was used in Exeter Cathedral and many local churches. Beer Stone was also exported beyond the county boundary.

A wide variety of fine-grained, basaltic rocks from the Permian succession around Exeter and Tavistock have been used for building and are locally known as 'trap'. The best-known quarries were at Pocombe and Posbury. Stone from these quarries was widely used in and around Exeter. Locally, intrusive dykes were also quarried for building stone.

Dartmoor granite remains Devon's principal building stone resource, widely used in Devon and across the country. The coarser grained, granitic elvan vein at Roborough was important locally as a building stone. The Lundy granite was worked briefly in the past for building stone.

4.1 SLATE

Slates from many localities across Devon have been used in the past for building, especially as walling and flooring materials. These were largely worked from Upper Devonian sequences such as the Gurrington Slate Formation and Tavy Formation (formerly known as the Kate Brook Slate Formation) in south Devon and the Ilfracombe Slate, Combe Martin Slate and Morte Slate formations in north Devon.

The only remaining active slate workings are in the Tavy Formation. This consists of hard greenish-grey slates with occasional thin sandstones. The quarries include Mill Hill, Longford and Yennadon (the latter two in Dartmoor National Park) which are in the Tavistock area, west of Dartmoor. The Gurrington Slate Formation produced purple, green and grey roofing slates, but is relatively weak and was restricted to use in the Newton Abbot/Ashburton area. The Morte Slate Formation consists of typically silvery smooth, purplish and greenish grey slates, locally silty with some siltstone and sandstone.

4.2 GRANITE

Granite was emplaced as an extensive igneous rock intrusion during Permian times and forms the upland moors and tors of the Dartmoor National Park in south Devon. Mostly the granite is coarsely crystalline, with large phenocrysts or megacrysts of potassium-feldspar, quartz and biotite mica, together with accessory minerals such as tourmaline. Some finer-grained granites do exist within the Dartmoor outcrop, but they have a relatively restricted occurrence.

The suitability of granite for construction varies; much of the granite formerly worked (including that used in Nelson's Column and New Scotland Yard) was coarse-grained with large whitish feldspar crystals. Fresh, unaltered granite is ideal for engineering uses, but it is hard and expensive to quarry. Partial alteration of granite by weathering and/or hydrothermal processes (which ultimately leads to the formation of kaolin) makes the granite easier to quarry for standard building stone. Currently, there is only one working quarry in the Dartmoor National Park: Blackingstone Quarry, near Moretonhampstead, on the northeast side of Dartmoor. This quarry has been in operation since at least 1912.

A number of smaller intrusions are associated with the Dartmoor Granite. These include fine-grained felsite known locally as 'elvans': these, including 'Roborough Stone,' were worked around Dartmoor for building stone and for roadstone aggregate The Meldon intrusion near Okehampton is a rare example of a lithium-bearing aplite. This is a pale grey microgranite consisting mainly of quartz, mica and feldspar, with small amounts of topaz and tourmaline.

5 Ball clay

Ball clays are fine-grained, highly plastic sedimentary clays, which fire to a light or near white colour. They are used mainly in the manufacture of ceramic whiteware and are valued for their key properties of plasticity, which makes them easy to mould, unfired strength and the fact that when fired they have a light colour. Normally sedimentary clays fire to a reddish colour. Some ball clays are also valued for their ability to readily disperse in water to produce fluid slips (high solids aqueous suspensions). Ball clays exhibit highly variable compositions and consist not of a single mineral but a mixture of predominantly three minerals: kaolinite, mica and quartz. The clay mineral kaolinite is the key component. The crystallinity of the kaolinite, in terms of being well-ordered (less plastic and coarser) or disordered (highly plastic and fine grained) also has a marked influence on ceramic performance. Fired colour is a function of iron and titanium contents, whilst unfired strength is largely related to fineness of particle size, as well as crystallographic ordering of the kaolinite. The wide variation in the mineral composition and particle size of ball clays, together with the crystallinity of the kaolinite, all result in differing ceramic and rheological (fluid) properties. This natural variability occurs both between and within seams, and from basin to basin. It is related to the origin of the clays and is caused mainly by differences in source rocks, the degree of weathering, and the environment in which the clays were deposited.

Ball clays, or 'plastic' clays, are relatively scarce globally because of the unusual combination of geological factors required for their formation and subsequent preservation. In the UK resources

are confined to three relatively small areas in the South West Region of England: the Bovey and Petrockstowe basins in Devon and the Wareham Basin of Dorset. The Bovey Basin is the most important source, both in terms of total sales and, more importantly, the diversity of the clays that are produced. The availability of a wide range of clays, some of which are of very limited extent, is rare. In 2004 the Bovey Basin accounted for 68% of total UK output of 964 797 tonnes and the Petrockstowe Basin 13%. Ball clays are used almost entirely as ceramic raw materials. The principal types of ceramic whiteware that contain ball clay are sanitaryware, floor and wall tiles, and tableware, and these sectors account for over 80% of total sales. Sanitaryware clays are the premium products of the ball clay industry and undergo more complex processing and thus command and a higher price. In 2004 over 83% of UK production was exported.

5.1 BOVEY BASIN

The Bovey Basin is a fault-bounded trough containing over 1100 m thickness of sediments of Palaeogene age. These sediments comprise clays, silts, sands, gravels and lignite of the Bovey Formation, which is divided into the informal Lower, Middle and Upper Bovey Beds, and which are further divided into members. Most of the commercially valuable ball clays are obtained from the top of the Middle Bovey Formation, but the lower part of the Upper Bovey Formation is becoming of increasing importance. Production is from the Abbrook to Goosehams members. The thick Lower Bovey Formation does not crop out at the surface and any ball clays that may be present are too deep to be of commercial interest. The sediments were deposited in a fluvio-lacustrine environment and exhibit considerable lateral variation in character. The ball clays were deposited in back swamps, which explains their fine particle size and the presence of colloidal carbonaceous matter. Sands were laid down by stronger currents, which often eroded or covered pre-existing ball clay deposits.

Ball clays in the Bovey Basin contain both well-ordered and disordered kaolinite, which accounts for the diversity of their properties. They include the whitest firing and most fluid UK ball clays, which is important for sanitaryware and tableware manufacture. They were probably derived from weathering profiles developed on the Dartmoor Granite and some resemble kaolin in character. The clays in the Abbrook Member are fine-grained and contain highly disordered kaolinites and were more likely to have been derived from mudstones and slates. The clays in the stratigraphically higher Southacre, Stover and Goosehams members contain higher proportions of coarser and better-ordered kaolinite.

The Bovey Basin has the largest permitted reserves and unpermitted resources of all the three basins, together with the greatest diversity of clays. Permitted reserves have been estimated at 63 million tonnes and the Basin will continue to be the major source of ball clay in the future. However, this gross figure includes a range of ball clay qualities and over 120 production clays are extracted from individual seams or parts of seams. Reserves of individual clay qualities that are essential for specific blends and applications may be more limited. Of particular importance will be the clays that form the basis of sanitaryware blends.

5.2 PETROCKSTOWE BASIN

The smaller Petrockstowe Basin in north Devon occupies an area of about 10 km^2. It is bounded by two northwesterly trending faults of the Sticklepath fault zone. The basin is filled with Palaeogene age Bovey Formation sediments. These comprise clays, silts, sands, gravels and lignites. The clays vary from relatively homogeneous sandy to very sandy clays with some bands of slightly sandy to ‘smooth’ clays. The clays are generally grey to grayish-brown to black and lignitic. Some of the clays are varved and consist of very silty clays interlaminated with clayey silts. Mineralogical composition of the Petrockstowe ball clays is variable and generally consists of illite, kaolinite, quartz and carbonaceous material (lignite), with smaller amounts of iron oxide, marcasite and siderite. Lignite is less common than in the Bovey Basin and typically occurs as scattered fragments, or finely disseminated in lignitic clay. Ball clay is worked in the

Petrockstowe Basin at two sites. WBB Minerals operate at Peters Marland at the northwestern end of the basin (Westbeare and Courtmoor quarries) and, at the southeast end, operation by IMERYS are close to Meeth (Glebe, Stockleigh Moor and Woolladon quarries). However, IMERYS ceased production at the end of 2004, because of the high costs of extraction.

6 Kaolin

China clay or kaolin is a commercial clay composed principally of the hydrated aluminosilicate clay mineral kaolinite. The commercial value of kaolin is based on the mineral's whiteness and its fine, but controllable, particle size which may be optimised during processing. Particle size affects fluidity, strength, plasticity, colour, abrasiveness and ease of dispersion. Other important properties include its flat particle shape, which increases opacity or hiding power, its soft and non-abrasive texture, due to the absence of coarser impurities, and its chemical inertness. These key properties distinguish kaolin from the other kaolinitic clays produced in Britain, such as ball clay and fireclay. The kaolinite content of processed kaolin varies, but is generally in the range 75 to 94%.

Kaolin resources in Britain are confined to the granites of South West England. The deposits are world famous for their size and quality. All the main granite intrusions have been worked to a limited extent in the past, but production has historically principally been based on the St Austell Granite and the southwestern margin of the Dartmoor Granite. The St Austell Granite is by far the most important source accounting for about 85% of total sales, which were 1.95 million (dry) tonnes in 2004, valued at nearly £200 million. The industry is of considerable national and regional importance. Of total sales some 88%is exported.

The kaolin deposits are of primary origin and were formed by the *in situ* alteration of the feldspar component of the granites. The kaolinisation process involved the decomposition of feldspar by hydrothermal fluids and surface weathering to form kaolinite and mica. Most other minerals are largely unchanged by this process. Extraction and processing consists essentially of separating fine-grained kaolinite from coarser, unaltered material, a process that results in large quantities of mineral waste. Kaolin has a range of uses but by far the most important, accounting for about 70% of total sales, is in papermaking. The kaolin performs two quite separate functions, as a paper filler and as a coating pigment. The ceramics industry is the second most important market but kaolin is also used as a filler in paint, rubber and plastics.

In Devon kaolin resources are confined to the extreme southwestern edge of the Dartmoor Granite and on the adjacent, but separate, Crownhill Down Granite. Kaolinisation has been intense and there is a higher proportion of sand and less rock than in the St Austell Granite. The kaolin has a lower iron and higher potash contents than in Cornwall and a large proportion of sales are used in ceramics, paints, plastics and rubber than in Cornwall. There is also a significant output of calcined kaolin for which the clays are well suited. Recently dry mining has been introduced in the Devon operations, which allows for more selective extraction and improved yields than traditional hydraulic mining.

The indicated resources shown on the map generally coincide with current production areas and adjacent ground. Planning permissions for kaolin extraction are more extensive as they also include land allocated for tipping. The projected life of the permitted reserves in Devon exceeds those in Cornwall. However, a critical factor is the availability of tipping space for the large quantities of sand and rock produced. Reserves will be constrained unless current sales of these wastes as secondary aggregates increase very substantially. There are other smaller areas of kaolinisation in the Dartmoor Granite some of which have been worked in a small way in the past. However, they are not shown on the map, as they are not thought to constitute any future resource.

The kaolinisation is adjacent to and extends into the Dartmoor National Park. In 2001, IMERYS Minerals and WBB Minerals announced that they were to relinquish their permissions in the Park because of the impact that would have on a sensitive area. This has now been carried out.

7 Brick clay

The term 'brick clay' is used to describe clay and shale used predominantly in the manufacture of bricks and, to a lesser extent, roof tiles and clay pipes. These clays may sometimes be used in cement manufacture, as a source of construction fill, and for lining and sealing landfill sites. The suitability of a clay for the manufacture of bricks depends principally on its behaviour during shaping, drying and firing. This will dictate the properties of the fired brick such as strength and frost resistance and, importantly, its architectural appearance.

Most facing bricks, engineering bricks and related clay-based building products are manufactured in large automated factories. These represent a high capital investment and are 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 textures is an increasingly common feature of the brick industry. Continuity of supply of consistent raw materials is of paramount importance.

Bricks are manufactured at two locations in Devon. Shales from the Crackington Formation (Upper Carboniferous age) are currently worked at Pinhoe Quarry in Exeter. The associated brick works produces facing and engineering bricks, predominantly for the market in South West England. The sequence consists of pale brown to pale grey shales with a small proportion (10%) of fine-grained sandstone. To improve its plasticity the shale is mixed with highly weathered shale (known locally as 'yellow dob') and allowed to weather for three months before being used in the brickworks. Brick clay resources in the Crackington Formation in the Exeter area only are shown on the map.

Middle Devonian slates are currently worked at Steer Point Brickworks (to the south east of Plymouth). This site manufactures red and pale coloured facing bricks. The sequence in the brick pit consists of variably weathered shale referred to by their colour (red, brown, blue and white). Ball clay is used to improve the plasticity of the clay blends used to produce pale coloured bricks. Brick clay resources from Middle Devonian slates in the Steer Point area are shown on the face of the map.

Ball clays from both the Bovey and Petrockstowe basins have been used locally for brickmaking in the past. Although this has now ceased, small amounts of ball clay are still sold for brickmaking elsewhere in South West England where they are blended with other, locally-won clays (see above). Although excellent brickmaking raw materials, ball clays used for this purpose will tend to be unsuitable for other, higher value, applications (see Ball Clay section). Demand from brickmakers elsewhere in England for these buff-firing clays is likely to increase in the future as supplies of fireclay, traditionally used to make high specification buff bricks, decline.

8 Hydrocarbons

8.1 CONVENTIONAL OIL AND GAS

Exploration for both gas and oil has occurred onshore in the east of the county, which lies on the extreme western limits of the Wessex Basin. Within this basin, major oil discoveries have been made in the Jurassic and Triassic rocks of Dorset. However, the main Mesozoic source and

reservoir rocks are absent in Devon. The lack of an adequate or proven older source rock means that the thick Permo-Triassic rocks encountered in the Crediton Trough are unlikely to be prospective for hydrocarbons.

The Gas Council is the only company to have explored for hydrocarbons in the county. No oil or gas shows were recorded in an exploratory borehole and the well was plugged and abandoned as dry (Table 1). As of late 2005, no active exploration licences held in the county.

8.2 COAL BED METHANE (CBM) AND UNDERGROUND COAL GASIFICATION (UCG) POTENTIAL

There is no potential for CBM or UCG in Devon because of the absence of significant coal resources.

Table 1. Hydrocarbon exploration wells drilled in Devon

Name	Date	Company	Status
Musbury no.1	1986	British Gas	Plugged & Abandoned, dry

9 Metalliferous mineralisation

The metalliferous deposits of Devon rival those of neighbouring Cornwall in variety, but are generally developed on a smaller scale. In the past, tin has been extracted from gravel deposits (tin stream or placer gravels), and by underground mining of veins in and around the Dartmoor Granite and to the west of Tavistock. Some tin-bearing veins also carry tungsten. The largest tin-tungsten deposit is at Hemerdon Ball near Plymouth, which was worked during the Second World War. Permission for the openpit winning and working of tungsten and tin and the associated tipping of waste was granted on the 5 June 1986 for a period of 35 years. There are no plans to open the mine and none are anticipated in the foreseeable future.

Copper, generally with arsenic, occurs in veins around the margin of the Dartmoor Granite and in the Tavistock district. In the past, both of these commodities have been extensively worked. The Devon Great Consols mine near Tavistock was, for a time in the middle of the 19th century, the largest copper producer in the world. Lead and silver were also worked in the Combe Martin area of north Devon. Iron ores are widely distributed and include hematite veins in the Devonian rocks of north Devon, 'bedded' (stratiform) deposits in the Ilsington area of eastern Dartmoor and hematite and hydrated oxide ores in the Devonian limestone of the Brixham area. Manganese ores have in the past been worked from Permian host sandstones and breccias in the district to the north of Exeter between Newton St. Cyres and Huxham. Barytes, used in the manufacture of paint, was worked throughout the first half of the 20th century from veins at Bridford in the middle Teign Valley.

Devon has also produced minor quantities of other metalliferous and spar minerals including antimony, zinc, uranium and fluorite. Traces of gold have been recorded from river gravels, particularly the lower reaches of the Dart, and from veins. The most notable vein occurrence is of gold-palladium in the Devonian limestone of Hope's Nose, Torquay. There has been recent exploration interest in gold in the Permian rocks of the Crediton Trough.

Mineral pigments, such as ochre, umber and red oxide, have been produced from deposits in the Ilfracombe, Ashburton and Brixham areas in the past. Carbonaceous shales and low-grade anthracite seams in the Bideford district yielded a pigment known as 'Bideford Black' that was

worked until the middle of the twentieth century. Veins in the north-eastern part of the Dartmoor Granite contain a soft graphite-like variety of hematite ('micaceous hematite' or 'shiny ore') that was much in demand for use in anti-corrosion paints.

10 Aims and limitations

The purpose of the maps in this series is to show the broad distribution of those mineral resources that may be of current or potential economic interest, and to relate these to selected nationally-recognised planning designations. The maps are intended to assist in the consideration and preparation of development plan policies in respect of mineral extraction and the protection of important mineral resources against sterilisation. They bring together a wide range of information, much of which is scattered and not always available in a convenient form.

The maps have been produced by collation and interpretation of mineral resource data principally held by the British Geological Survey. Information on the extent of mineral planning permissions has been obtained from the relevant Mineral Planning Authority (MPA). Some of these permissions may have lapsed or expired. The status of individual areas can be ascertained from the appropriate MPA. Location information on national planning designations has been obtained from the appropriate statutory body (Countryside Agency, English Nature and English Heritage). For further information the relevant body should be contacted.

The mineral resource data presented are based on the best available information, but are not comprehensive and their quality is variable. The inferred boundaries shown are, therefore, approximate. Mineral resources defined on the map delineate areas within which potentially workable minerals may occur. These areas are not of uniform potential and also take no account of planning constraints that 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. Extensive areas are shown as having no mineral resource potential, but some isolated mineral workings may occur in these areas. The presence of these operations generally reflects very local or specific situations.

The maps are intended for general consideration of mineral issued and not as a source of detailed information on specific sites. The maps should not be used to determine individual planning applications or in taking other decisions on the acquisition or use of a particular piece of land, although they may give useful background information which sets a specific proposal within context.

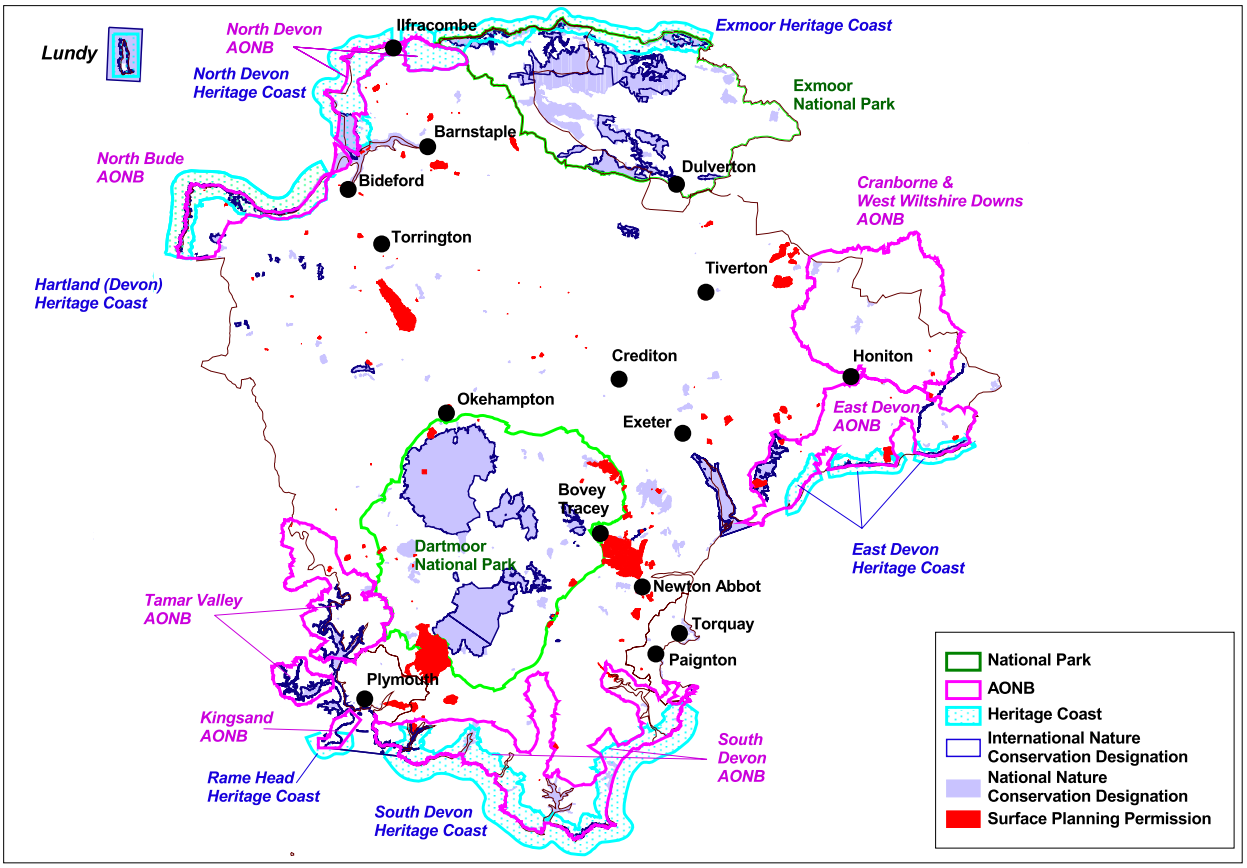

Figure 2. Surface mineral planning permissions and environmental designations.

11 Planning permissions for the extraction of minerals

The extent of all known extant and non-extant planning permissions for the extraction of minerals is shown on the map, irrespective of their current planning or operational status. The polygons were supplied as digital files by Devon County Council and also digitised by BGS from Plotting Sheets and other documents supplied by Plymouth City and Torbay councils and Dartmoor National Park. In addition, planning permission information was digitally captured from Ministry and Housing and Local Government maps for the area and incorporated into the data. This data has been checked and amended by the local authorities shown below. Any queries regarding the sites shown should be directed to these authorities. The polygons cover active, former and restored mineral workings and, occasionally, unworked deposits.

Planning Permissions represent areas where a commercial decision to work mineral has been made, a successful application has been dealt with through the provisions of the Town and Country Planning legislation, and the permitted preserve will have been depleted to a greater or lesser extent. The current planning status is not qualified on the map, but is available in the underlying database.

Contact addresses:

Devon County Council, Environment Directorate, Lucombe House, County Hall, Topsham Road, Exeter EX2 4QW, Tel:01392 383233, Fax: 01392 382135, web address: www.devon.gov.uk

Plymouth City Council, Planning Services Department, Civic Centre, Royal Parade, Plymouth PL1 2EW, Tel: 01752 668000, Fax: 01752 304931, web address: www.plymouth.gov.uk

Torbay Council, Environment Services Department, Roebuck House, Abbey Road, Torbay TQ2 5DP, Tel: 01803 201201, Fax: 01803 208858, web address: www.torbay.gov.uk

Dartmoor National Park, Planning and Community Department, "Parke", Haytor Road, Bovey Tracey, Newton Abbott, TQ13 9JQ, Tel: 01626 832093, Fax: 01626 834684, web address: www.dartmoor-npa.gov.uk

Exmoor National Park, Planning and Community Department, Exmoor House, Dulverton TA22 9HL, Tel: 01398 323665, Fax: 01398 232150, web address: www.exmoor-nationalpark.gov.uk

Appendix

TOPOGRAPHIC BASE

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CONSTRAINT INFORMATION

Constraint information published on the accompanying map has been provided from the various agencies listed below; any enquiries on this information should be addressed to the relevant agency.

English Nature

Digital SSSI, SAC, SPA, RAMSAR and NNR boundaries © English Nature 2005

Contact address: English Nature, Northminster House, Northminster, Peterborough PE1 1UA. Tel: 01733 455000. Fax: 01733 455103. Web page: www.english-nature.org.uk

English Heritage

Positions of scheduled monuments at 25th September 2003.

The majority of monuments are plotted using a centred NGR symbol. Consequently the actual area and/or length of a monument protected by the legal constraints of scheduling cannot be represented here. Monuments scheduled since that date are not accounted for. © Copyright English Heritage.

Contact address: English Heritage, 23 Savile Row, London W1S 2ET. Tel: 0207 973 3132. Web page: www.english-heritage.org.uk

Countryside Agency

Digital AONB boundaries © Countryside Commission 1986 (now Countryside Agency)

Contact address: Countryside Agency, John Dower House, Crescent Place, Cheltenham, Gloucestershire GL50 3RA. Tel: 01242 521381. Fax: 01242 584270. Web page: www.countryside.gov.uk

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