British Geological Survey

DETR

Mineral Resource Information for Development Plans

Cornwall: Resources and Constraints

BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WF/97/11
Mineral Resources Series

Mineral Resource Information for Development Plans Phase One Cornwall: Resources and Constraints

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This report accompanies the 1:100 000 scale map:
Cornwall Mineral Resources

Cover photograph
China clay extraction by high pressure monitor. Courtesy of ECC International Europe

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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 Regions (DETR) Research Project 'Mineral Resource Information for Development Plans.'

The report and accompanying map relate to the County of Cornwall. They 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 a digitally-generated summary map, Mineral Resources. The map is produced at 1:100 000 scale, 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. In the wider context of sustainable development, mineral resource data are also required for resource evaluation and planning and for the establishment of baseline data needed for environmental impact studies and environmental guidelines. Moreover, knowledge of the extent and quality of mineral resources, and there rate of extraction can help to value them as national assets, to ensure that the capital they represent is managed properly and rates of depletion monitored. This will ensure that a sustainable pattern and standard of development is achieved.

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, the Environment Agency, the Countryside Commission, 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 resources covered are china clay, china stone, igneous rock, serpentinite, sandstone, slate, sand and gravel, metalliferous and related minerals, geothermal energy, oil and gas, and secondary aggregates.

INTRODUCTION

'........ it will become increasingly important to have reliable information about the nature, quantity and location of mineral resources, as workable reserves in environmentally acceptable areas become scarcer.'

Sustainable Development: The UK Strategy.
Government's response to the Rio Earth Summit.

This report is one of a series that has been prepared by the British Geological Survey for various administrative 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 area of Cornwall and should be used in conjunction with the Mineral Resources Map of the county which accompanies this report. The report and map delineate and describe the mineral resources of current or potential economic interest in Cornwall and relate these 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, by providing 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 minerals extraction or on proposals which might sterilise resources.

The report and map represents the situation at 1st January 1997. All the data are held in digital form which can be readily updated and revised on a regular basis and 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 county Mineral Resource Map is at 1:100 000, which is a convenient scale for overall display and to show the information on a legible topographic base.

Our industrialised society is highly dependent on minerals, and their extraction and use makes a major contribution to wealth creation, the nation's infrastructure and the quality of life of individuals. Mineral resources are, therefore, national assets. However, minerals can only be worked where they occur and their 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 artefacts or due to amenity impact.

Basic mineral resource information is essential to support mineral exploration and development activities. In the wider context of sustainable development, mineral resource data are also required for resource evaluation and planning, and for the establishment of baseline data 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 to value them as national assets, to ensure 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 achieve a balance between competing objectives. Achieving that balance requires adequate data on the relevant competing objectives, including the extent and details of mineral resources. As workable resources in environmentally acceptable areas are becoming scarcer, it will be 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. Relevant authorities must produce either a Minerals Local Plan or mineral policies within a unitary development plan. 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 a local plan or unitary development plan, which sets out the policies and proposals against which mineral planning applications and appeals are determined. Such 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 every five years 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 (MPG1).

The key elements of a minerals local plan or 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 famework within which the minerals industry may make planning applications

- 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 that information on the extent, quality and, if possible, quantity of mineral resources is an essential prerequisite for the production of mineral local plans or unitary development plans, both in the context of identifying areas of future mineral working and the longer term objective of the protection of important mineral resources against sterilisation. 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)

An additional and important objective is that the data should be capable of easy revision and update. The map thus brings together a wide range of information, much of which is scattered and not always available in a consistent and convenient form. 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, the Environment Agency, the Countryside Commission and English Nature), environmental interests and the general public.

Mineral resource classification

Mineral resources are natural accumulations of minerals, or bodies of rock, that are, or may become, of potential economic interest as a basis for the extraction of a commodity. However, 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. Mineral resources are thus economic as well as physical entities. The assessment of mineral resources is a dynamic process which must take account not only of geological reinterpretation, but also of the continually evolving demand for minerals, or specific qualities of minerals, due to changing economic, technical and environmental factors. Areas that may be of potential economic interest as sources of minerals may thus change with time.

With the notable exception of china clay resources, the map of Cornwall shows 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 and also take no account of the planning constraints that may limit their working. However, more comprehensive information on the extent of china clay resources, based on systematic drilling, sampling and testing, has been made available by the china clay industry. This has allowed the extent of **measured and indicated resources** to be shown within the current production areas. Elsewhere inferred resources of china clay are shown.

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** shown on the map 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 currently 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 mineral resource information has been produced by the collation and interpretation of data held by the British Geological Survey and provided by the china clay industry. The resource areas are taken, with some generalisations, from available BGS 1:50 000 scale maps. These are based on 1:10 560 or 1:10 000 scale surveys, which cover the whole county. In general, the more recent the survey the more detailed it is likely to be. Sources of information are given in the selected bibliography and in the appendices.

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 they produce, are shown on the map and listed in Appendix 1.

The extent of all known mineral planning permissions is shown on the Mineral Resources Map and a distinction is made between surface and underground permissions. These include mineral permissions granted since 1st July 1948 and IDO 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 mineral resource may have been depleted to a greater or lesser extent.

The mineral planning permission data were obtained from Cornwall County Council. The present physical and legal status of individual permissions is not qualified on the map 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 sites where the permission still exists. Sites which have been restored have not been separately identified. A mineral planning permission may extend beyond the mapped resource as it may make provision for operational land, including plant and overburden tips, 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 Cornwall County Council (Appendix 2).

Environmental designations

The map shows the extent of selected, nationally-designated planning constraints as defined for the purposes of this study. These constraints 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 mineral planning authority.

The constraints shown on the map are:

- Area of Outstanding Natural Beauty (AONB)
- Heritage Coast
- National Nature Reserve (NNR)
- Site of Special Scientific Interest (SSSI)
- Scheduled Monument

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 Mineral Planning Authority (Appendix 2).

Digital data on AONBs and the Heritage Coast have been obtained from Cornwall County Council, 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. These are plotted using a centred NGR symbol and consequently the actual area/length of a monument protected by the legal constraints of scheduling cannot be represented on the map. 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. For further information the relevant agency should be contacted (Appendix 2).

MINERAL RESOURCES

The Cornish peninsula is underlain by a variety of rocks including slate and granite, which contribute to the special character of the county's landscape and coastal scenery. These rocks also host the mineral wealth that has been such an important feature of the economic life of Cornwall from the times of the ancient tin workers to the important china clay industry of the present day.

The nature and distribution of Cornwall’s mineral resources reflect the complex geological history of the area. Perhaps more than in any other part of Britain, the mineral resources that occur in the county are directly related to a specific geological event. This event was the Variscan orogeny, or mountain building episode, that occurred some 300 million years before the present, when two continental masses were in collision along an extensive common boundary. The period of compression that resulted caused folding and fracturing of strata of Devonian and Carboniferous age (405 to 290 million years before the present) and also melting of the deeper crust resulting in the intrusion of large masses of coarsely crystalline granite of early Permian age (Figure 1). Associated with the emplacement of the granite was extensive metal mineralisation and the start of the alteration processes which subsequently led to the formation of the world class china clay deposits of the area. Uplift of the deformed strata to form a mountain chain was followed by a long period of erosion during the Permian and Triassic eras, when the area that is now South-west England was an arid desert in equatorial latitudes. The grey slate and granite that is now seen around the coast and in inland quarries in present day Cornwall represents the roots of the former Variscan mountain range exposed by deep

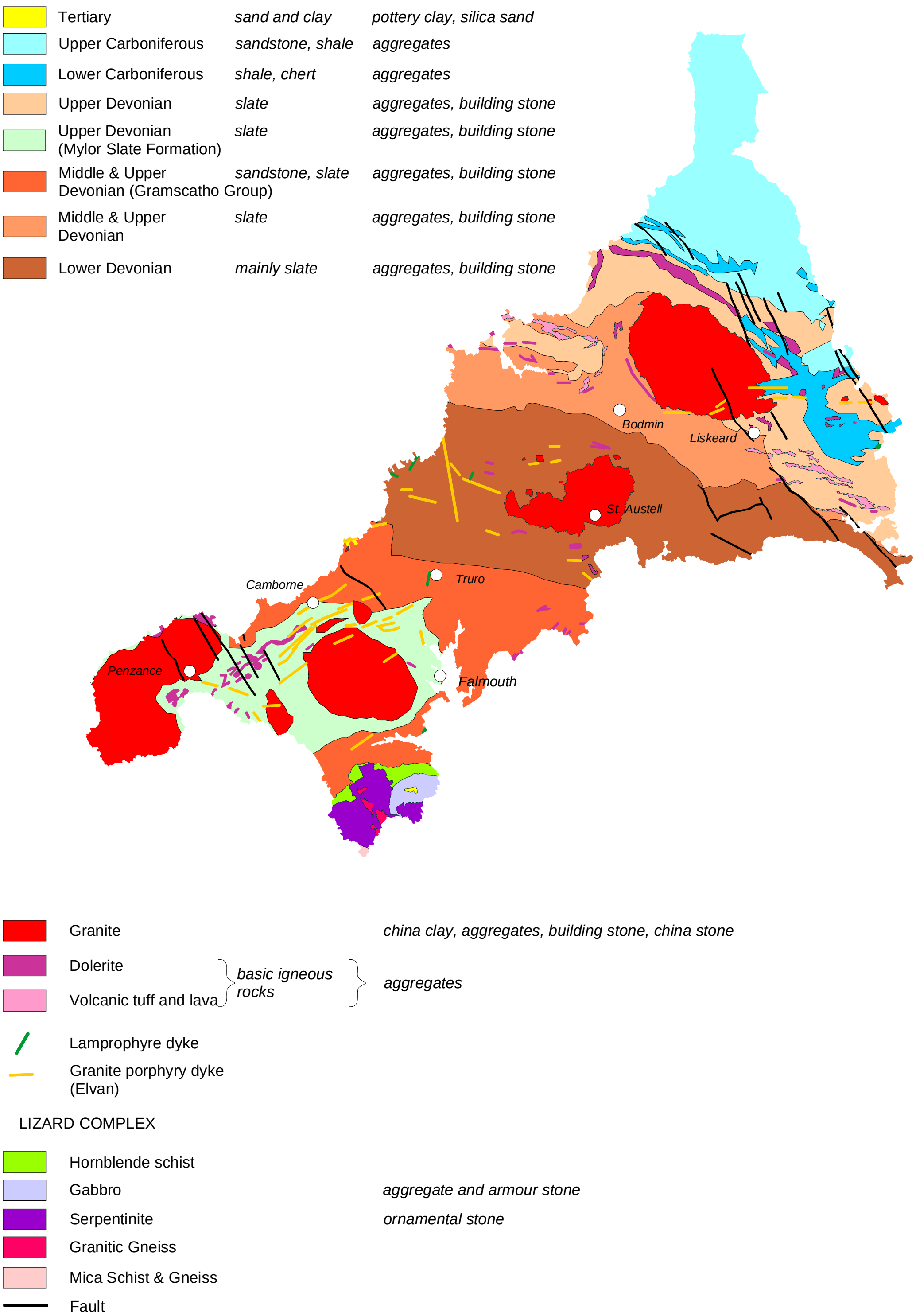


Figure 1 Simplified geological map of Cornwall, with commodities related to geology

erosion. Deep weathering during the Mesozoic and Palaeogene (Tertiary) continued the process of china clay formation. During the Pleistocene period, ice sheets did not cross the land mass of Cornwall and in contrast to most other counties in Britain there are no significant resources of sand and gravel in the county.

Metalliferous minerals have been worked in Cornwall since the Bronze Age, when tin was first used by Ancient Man to harden copper. Mining activity reached a peak in the second half of the 19th century and the remains of mining works from this and earlier periods are scattered thickly throughout the landscape and make an important contribution to the county's industrial heritage. Cornwall has remained Britain's foremost metal mining area and currently supports the only important metal mine in the country.

Mineral production in the county has, however, been dominated by china clay during the 20th century. With a rapidly rising demand for paper, particularly for high-quality colour printing, there has been a commensurate increase in the production of china clay since the Second World War. Production peaked at nearly 3.3 million tonnes in 1988, although has declined more recently. Cyclical downturns in demand has affected production in recent years, and the industry is also facing increasing competition from alternative white pigments and also from major, new overseas deposits coming on stream. However, the Cornish china clay industry is based on large, high-quality resources and coupled with innovative processing technology is well placed to meet this competition with the new and improved grades of china clay. Moreover, Cornwall's china clay resources have provided the basis for the expansion of the domestic industry overseas and ECC International is now the world's leading producer of china clay (kaolin).

The period since 1950 has also seen the dimension stone industry, based primarily on granite, come under pressure from changes in construction methods and imports. A number of operations have developed to produce crushed rock aggregates, with other quarries closing down.

At present, the most important resource in the county is china clay. The demand for aggregate is also of importance. In the current economic climate the demand and constraints on the production of these materials will be the most prominent issue in the mineral planning process in the future. In addition, despite the low level of metal exploration currently taking place future activity cannot be precluded if metal prices increase. Exploration for gold is currently being undertaken in east Cornwall.

CHINA CLAY

China clay, or kaolin as it is internationally known, is a commercial term used to describe a white clay composed predominantly of the clay mineral kaolinite. Britain is the world's second largest producer and exporter of kaolin after the USA. Total sales amounted to 2 281 000 dry tonnes (i.e. on a moisture free basis) in 1996 of which some 85 per cent was exported, principally to Western Europe. The total value of china clay production is in excess of £200 million a year and the industry is thus of considerable economic importance, both locally and nationally.

China clay exhibits a marked whiteness and fine particle size in its natural state, properties which are optimised during subsequent processing. It is on these two key properties that the commercial value of china clay principally resides and which distinguishes it from other kaolinitic clays, such as ball clay and fireclay.

Although originally extracted almost exclusively for the manufacture of fine ceramics, today some 80 per cent of total china clay sales is consumed by the paper industry as a paper filler and for paper coating, in roughly equal proportions. A further 12 per cent is used in ceramics manufacture, and the remaining 8 per cent as a filler in paint, rubber, plastics and for a range of miscellaneous applications. In the Western European paper market the industry is facing increasing competitive pressures, both from imports of kaolin from the USA and, more recently, from the Amazon Basin in Brazil, and also from alternative white pigments, in particular, fine ground calcium carbonates.

Kaolinisation

The china clay resources of Britain are confined to the granites of South-west England, and Cornwall accounts for some 90 per cent of total UK production. The deposits are of primary origin and were formed by the selective alteration (kaolinisation) of the feldspar component of the granites by acid aqueous fluids to form an aggregate of kaolinite and secondary white mica. Sodium feldspar (plagioclase) was preferentially decomposed and potassium feldspar remained largely unaltered, except in areas of extreme kaolinisation. Other minerals also remained largely unchanged. Smectite (a clay mineral), may also occur in minor quantities but its presence, even in very small amounts, is commercially important as it has a detrimental effect on the performance of paper-coating clays, although it increases the strength of ceramic clays which is beneficial in some ceramic bodies. The properties of the china clay deposits varies both within and between pits, and blending to achieve consistency is of critical importance.

The principal zones of kaolinisation are related to permeable fracture and vein systems through which the kaolinising fluids circulated and the most intense alteration is a function of the frequency and continuity of these fracture systems. The kaolinised zones are funnel or trough-like in form, narrowing downwards, but merging of funnels has resulted in more extensive zones of kaolinisation (Figure 2). Kaolinisation may extend to depths of over 200 m, and this has important practical implications for china clay production since opportunities for progressive backfilling of pits are limited. However, the main kaolinisation took place close to the roof of the granite intrusions and the present distribution of deposits is believed to reflect the degree of erosion that has taken place. The large size and areal extent of the deposits in the St Austell Granite suggests that these deposits have not been eroded as deeply as elsewhere (Bristow and Exley, 1994).

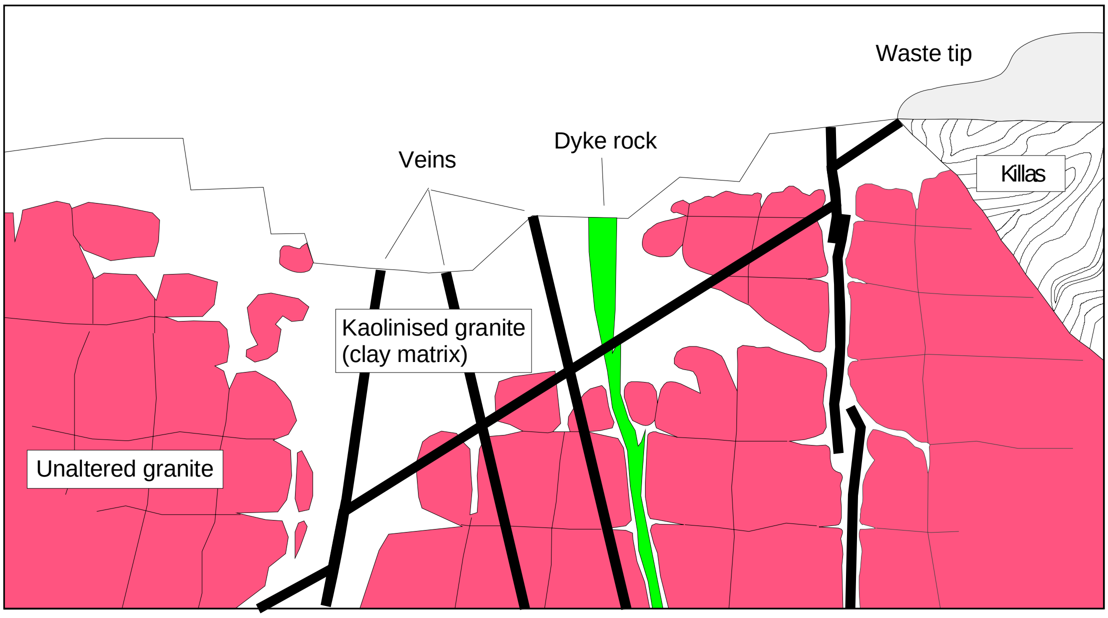


Figure 2 Generalised cross section of a china clay pit *(after Bristow and Exley, 1994).*

The kaolinised zones contain a variety of rock types from hard, unaltered granite through to a soft kaolinised 'clay matrix' consisting of a friable aggregate composed principally of quartz, mica, unaltered feldspar, tourmaline and very fine-grained kaolinite which mainly occurs in the < 20 μm fraction. However, coarser-grained kaolinite also occurs. The kaolinite content of the clay matrix is variable but typically in the range 15–25 per cent. However, because of the presence of hard, unaltered granite and quartz/tourmaline veins, known locally as 'stent', overall recoveries of china clay may be as low as 10 per cent. The average waste to clay ratio in the largest pits is some 9:1. Consequently large areas are required for waste disposal and this is a continual problem for the industry.

Mining and refining

China clay mining is a combination of hydraulic mining using water jets to breakdown the kaolinised granite and ripping, drilling and blasting of the unkaolinsed granite for subsequent removal. Processing involves the separation of the fine kaolinite particles from coarser-grained impurities by a series of refining techniques, and following blending, the clay is dried or distributed in slurried form. Methods used to improve the brightness (whiteness) of specific grades of clay, include chemical reductive bleaching and/or the removal of iron-bearing impurities using superconducting magnets. To meet increasing competition, the industry is moving towards more consistent production of higher quality and more specialised grades of clay.

High pressure jets of water are used to disaggregate the kaolinised granite and disperse the kaolinite, together with the other minerals, into a slurry. Harder rock types, such as unkaolinised granite are removed by dump trucks. Coarse sand greater than 250 μm in diameter is removed from the slurry by sand pits, spiral classifiers or bucket wheel desanders, the latter now being more commonly used. The disposal of the sand, and other waste products, is a major and increasing problem because of the land area it requires and its environmental impact. The < 250 μm material then passes to hydrocyclones where the > 53 μm fraction consisting of mica, but with some quartz, feldspar and coarse kaolinite, is removed and pumped to the mica residue dams for disposal.

Subsequent refining is carried out in a succession of refining tanks (hydroseparators) where the > 15 μm fraction consisting largely of mica and coarse-grained kaolinite is discharged. This material is now reprocessed for the recovery of the coarse kaolinite. The large and high cost refining tanks are now being replaced by multi-stage hydrocyclone plants which have the added advantage of a higher recovery of china clay. The fine product from the refining tanks is essentially 45 per cent < 2 μm and is marketed as a general purpose filler. If the clay is of adequate quality it is further treated in centrifuges which allow separation at very much finer particle sizes than hydrocyclones. The very fine-grained product from centrifuging is at least 75 per cent < 2 μm which is sold for paper-coating applications.

As a result of the overlap in particle-size between kaolinite and mica there has been some loss of the coarser kaolinite particles into the oversize fraction, both at the centrifuge stage and from the hydroseparators/hydrocyclones. This kaolinite was formerly rejected to the waste micaceous residue dams. The kaolinite contained in these residues is both too coarse to be sold as a commercial grade of china clay and is also contaminated with abrasive impurities such as quartz, feldspar, mica and tourmaline. Maximising the yield of mineral from a deposit, and thus minimising waste, is a fundamental objective of sustainable development. More importantly, however, it improves the economics of an operation by increasing product recovery. The development of innovative processing technology by ECC International Europe has, however, allowed the coarse kaolinite particles formerly rejected to be recovered by ultrafine froth flotation followed by low-solids sand grinding to break down the kaolinite aggregates to maximise recovery in the < 2 μm fraction (Pemberton, 1989). By processing former waste streams, the recovery of china clay from the clay matrix now exceeds 90 per cent as opposed to only 70 per cent a few years ago (Lofthouse, 1995). Moreover, these recovered clays can be tailored, or ‘engineered’, to meet a wide range of applications. This technology has also allowed old micaceous residue dams to be to be retreated for the recovery of the coarse kaolinite thus providing additional resources of china clay.

Resources

Whilst all the main granite intrusions have been worked to some extent in the past, kaolinisation has a very uneven distribution. Historically, china clay production has been based principally on the central and western parts of the St Austell Granite and on the south-western margin of the Dartmoor Granite in Devon. The St Austell Granite is by far the most important source, accounting for some 83.5 per cent of total production and most of the high-brightness, speciality paper-coating grades. In Cornwall, the only other source of china clay is the Bodmin Moor Granite which accounts for some 6.3 per cent of total production. Minor production on the Land’s End Granite at Bostraze ceased in 1991. The china clay deposits of South-west England have yielded over 150 million tonnes of marketable product since production began in the mid-18th century (Figure 3).

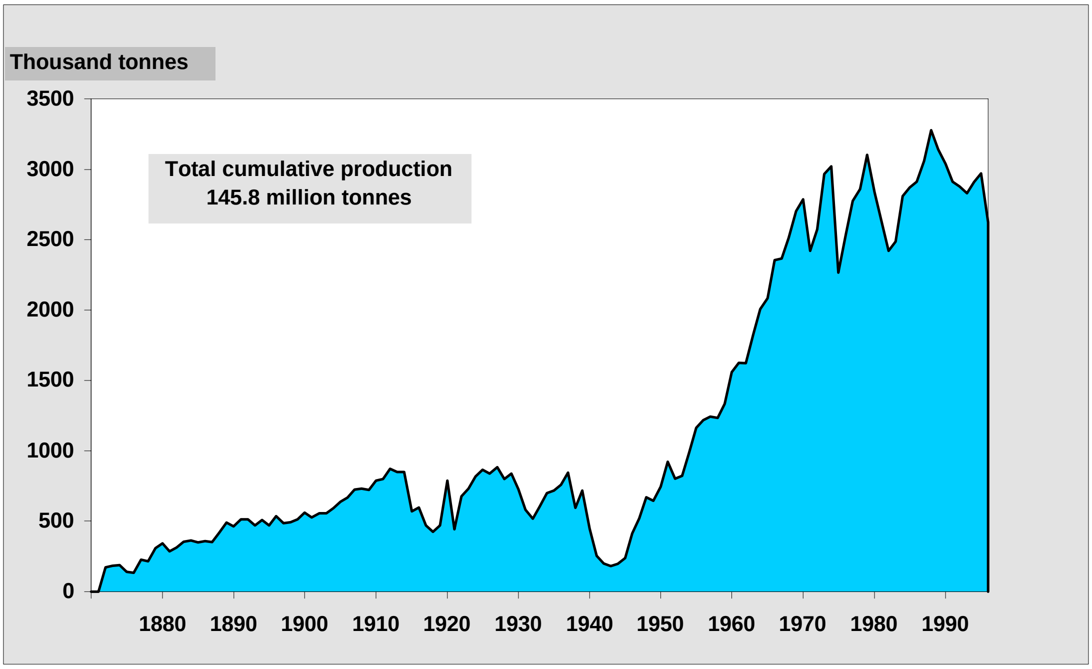
The St Austell Granite covers an area of about 93 km^2 and is extensively kaolinised in its central and western parts over and area of about 63 km^2. The majority of the pits are situated in this area which is some of the most intensively worked mineral-bearing land in Britain. The eastern part of the granite is relatively unaltered and consists of coarse-grained granite. The western part of the St Austell Granite has traditionally supplied ceramic clays, the central part paper-coating clays and the eastern part filler clays. However, blending and improved processing technology now make this somewhat of an oversimplification.

Plate 1 Aerial view of the Littlejohns china clay pit, St Austell Granite showing hydraulic mining and bucket wheel desanders (foreground) and reclaimed waste tips (background). (Courtesy of ECC International Europe).

Production of china clay on the Bodmin Granite has been about 200 00 tonnes a year in recent years, most of which is used as a paper filler. There are current workings at Park [SX 194 708] and Stannon [SX 128 812], but abandoned pits are widespread in the western part of the granite. Most were abandoned prior to the First World War, but Hawkstor [SX 150 747] closed in 1971 and Glynn Valley [SX 143 718] in 1942.

Kaolinisation is also found in numerous, but relatively small, areas elsewhere. Within the Land's End Granite, localised deposits have been worked in the past. Most closed many years ago, but a small pit at Bostraze [SW 385 316], east of St Just, remained in production until 1991. Within the Tregonning-Godolphin Granite (site of the first discovery of china clay) deposits were worked intermittently during the 19th century, but all were closed by 1905 (Smith, 1992). Small-scale production was also recorded at Belowda Beacon, a small granite body north of the St Austell Granite, and from the Carnmenellis Granite. None of these deposits have been of significant economic importance in the past and future china clay production in Cornwall is likely to be confined to the St Austell and the Bodmin Moor granites.

Two classes of china clay resources have been defined on the mineral resources map depending on the degree of confidence in the data presented; these are (i) measured and indicated resources and (ii) inferred resources. Measured and indicated resources are those resources which are known to occur and generally coincide with the current production areas where detailed exploration and evaluation has been undertaken by the industry. Planning permissions for china clay extraction, although generally coincident with these areas, are more extensive because of the need to allocate additional land for tipping and/or plant development that will not sterilise resources. A programme of ongoing evaluation is undertaken by the industry and these resource areas may expand as additional information becomes available. Inferred resources are those areas where the industry believe that china clay deposits may occur. They include areas which have been worked in the past, but there are no current plans to develop these resources.



Note: Recent figures for 'dry tonnes' have been recalculated to conform with earlier data.
Source: *United Kingdom Minerals Yearbook. British Geological Survey.*

Figure 3 United Kingdom: China clay production 1872–1996.

Additional resources of china clay occur in micaceous residue dams which contain variable amounts and qualities of kaolinite, depending on the source and age of the residues. Three such dams are currently being worked within the St Austell Granite and others may be worked in the future. Proved reserves of china clay in Cornwall and Devon are sufficient for at least 25 years at current rates of production and the industry has a long term future.

CHINA STONE

'China stone,' or 'Cornish stone,' is a largely unkaolinised granite and consists primarily of feldspars and quartz. It is the only source of feldspathic raw material produced in Britain and is used mainly as a ceramic flux in the manufacture of bone china. Although the Cornish china stone industry is overshadowed by its much larger neighbour, its origins stem from the same discovery, by William Cookworthy, of the raw materials for the manufacture of porcelain. China stone was first recognised with china clay in the Tregonning-Godolphin Granite and then, subsequently, in the St Austell Granite, where production has continued to the present day.

China stone consists principally of sodium feldspar, potassium feldspar, quartz and mica, together with small amounts of fluorite, topaz and apatite. Depending on the degree of alteration of the feldspars, there is also a proportion of kaolinite present (Smale, 1979). The absence of iron-bearing minerals, such as biotite and tourmaline, make china stone suitable for use as a flux in the manufacture of a range of pottery bodies and glazes, although today it is mainly used in the manufacture of bone china. Small amounts are also used as a filler. There are a number of varieties named on the basis of their hardness and physical appearance, such as Hard Purple and Hard White. As the change from kaolinised granite to hard china stone is gradational and takes place over a few metres, the lump stone is produced by hand selection of loosened blocks, for subsequent crushing and blending.

The industry was formerly much larger than it is today, with peak production of some 70 000 tonnes/year in the early 1950s. However, production declined in face of competition from imported feldspars. The Clean Air Act in 1960 restricted the emissions of hydrofluoric acid gases and other pollutants during pottery manufacture and consequently a defluorinated stone (DF Stone), from which fluorite and mica had been removed by flotation, was introduced by English China Clays. Sales to the Potteries increased to some 26 000 tonnes a year, but the material proved not to be competitive and production ceased in 1973. Since then the sole producer of china stone has been Goonvean Ltd with production based on the Great Wheal Prosper pit located between Treviscoe and Nanpean. In 1990 the company reintroduced a defluorinated stone from which fluorite has been removed by flotation. Current production of all grades of china stone is some 8 000 tonnes a year.

IGNEOUS ROCK

Granite

Granites are the most extensive igneous rocks in Cornwall and occur as four large intrusions ('plutons'), together with a number of smaller bodies. From west to east the larger granites are those of Land's End, Carnmenellis, St Austell and Bodmin Moor. The smaller bodies include Godolphin/Tregonning, St Michael's Mount, Carn Marth, Carn Brea, St Agnes, Cligga Head, Castle-an-Dinas, Belowda, Kit Hill, Hingston Down and Gunnislake. Granite typically forms the higher ground of Cornwall, with tracts of moorland such as those of Bodmin Moor and St Just-in-Penwith.

Granites are composed of the minerals feldspar, quartz and mica, generally with some tourmaline. There is considerable variation in the appearance of the granites from one locality to another, with fine-grained equigranular types contrasting with very coarsely crystalline varieties in which scattered individual feldspar crystals exceed 100 mm in length. The granites have provided an attractive source of dimension stone and their historical importance as a building material is reflected by the large numbers of disused quarries throughout the county. In the 19th and early 20th centuries granite was much in demand for construction, particularly for civic, institutional and commercial buildings, and was exported in considerable volumes. Smaller granite quarries provided local building material and roadstone.

Igneous rock accounts for almost all the production of crushed rock aggregate in Cornwall (Figure 4). Granite accounts for the major proportion of the crushed rock output with active quarries located on the Land's End, Carnmenellis, St Austell and Hingston Down granites, and china clay waste also providing a contribution. Much smaller quantities are quarried for building and dimension stone. Critical factors in selecting quarry sites for dimension stone include the spacing and attitude of joints in the granite, and the extent and intensity of secondary alteration, such as weathering, iron-oxide staining and clay alteration (kaolinisation). The Hantergantick and De Lank quarries (Plate 2), near the western margin of the Bodmin Granite, are an important source of dimension stone. Silvery grey, uniform and fine-grained granite is produced to a wide range of finishes and is used for cladding and floor covering both internally and externally. Typically the granite has a crushing strength of 194.4 MN/m^2 and a bulk density of 2640 kg/m^3.

The types of granite worked for aggregate use vary considerably in their texture and appearance, but most are coarse-grained biotite- or biotite-muscovite granites, some with prominent large potassium feldspar crystals ('megacrysts'). Fine-grained granites, also known as microgranites, are less common and the only example worked in any volume at present is at Hingston Down, near Gunnislake. The available technical data demonstrate that there is considerable variation in rock strength from one site to another (e.g. in a dataset provided by Cornwall County Council, soaked ten per cent fines values[1] range from 100 to 250 kN), while resistance to polishing is relatively low (PSV 48 to 56)[2]. These data, together with data supplied by the quarrying industry, suggest that the strength and PSV are independent of granite variety and texture, and, instead, reflect local variations in weathering and secondary alteration. For these reasons, the Resource Map does not distinguish between the fine- and coarse-grained granite varieties in the same manner as the published geological maps.

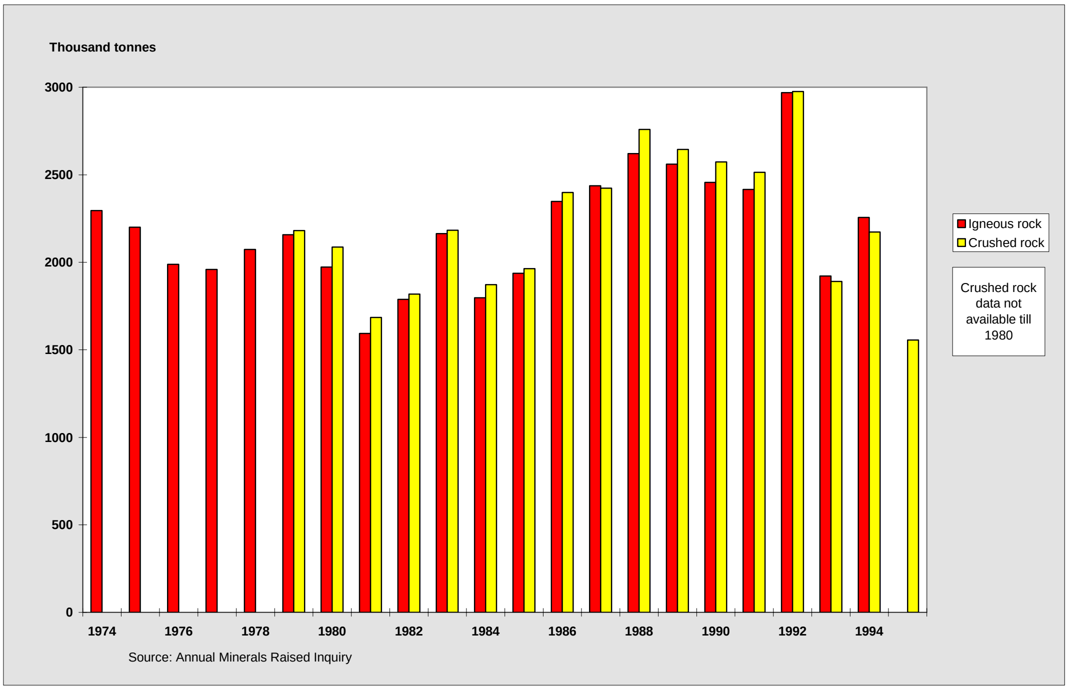


Figure 4 Cornwall: Production of igneous rock and crushed rock aggregate, 1974–1995.

[1]*Ten per cent fines value. Resistance of an aggregate to crushing, as measured by the force in kN applied, is the ten per cent fines test. The larger the value, the more resistant to crushing is the rock.*

[2]*Polished Stone (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.*

Plate 2 Dimension stone produced from the Bodmin Moor Granite at the De Lank quarry operated by Natural Stone Products Ltd.

Basic Igneous Rock

A wide variety of basic igneous rocks, including basalt, dolerite, gabbro and picrite, are known collectively as 'greenstone' in Cornwall. They occur within the Devonian and Lower Carboniferous slate and sandstone sequences as variably-sized bodies of extrusive (i.e. volcanic) basic igneous rock and their intrusive equivalents (dolerite sills and dykes). Most of the greenstones are harder and more resistant to erosion than their slate hosts so that they tend to form positive features in the landscape. More extensive outcrops of gabbro occur on the Lizard Peninsula. Many disused quarries are situated on these outcrops and demonstrate the widespread use which was made of greenstone for building and roadmaking. Considerable variation in lithology exists: the coarsely crystalline gabbros of the Lizard contrast with microcrystalline lavas from east Cornwall. The greenstone may be relatively unaltered (all show some low-grade metamorphism) or may show extreme alteration, as in the carbonated tuffs of north Cornwall (most original minerals replaced by calcium/iron carbonates) or the thermally-indurated greenstones (hornfels) in places adjacent to the larger granite masses. Within some of the greenstone masses, particularly those of volcanic origin or those which have been subjected to secondary carbonate replacement, weathering produces zones of weak rock varying from slightly lowered crushing strength to the total breakdown of the rock to a mass of brown iron oxide-rich clay. These variations are less evident in the larger masses of intrusive greenstone and in those which have been affected by extreme thermal metamorphism, which typically increases their crushing strength due to recrystallisation.

Just as the lithology and mineralogy of greenstones is variable, so too are their technical properties and thus their suitability for use as aggregates. The greenstone hornfels formerly worked at Penlee, near Newlyn in west Cornwall, has a very high strength with a quoted dry ten per cent fines value of 354 kN, PSV 44 and AAV 1.5[3] This rock was mainly worked for roadstone and shipped out from an adjacent jetty in boats with capacities up to 2 500 tonnes. Data for other sites supplied by Cornwall County Council show the following ranges: PSV 48 to 59, and soaked ten per cent fines 210 to 335 kN. Dolerites are quarried in the eastern part of the county for general aggregate use, including road surfacing. The Lizard gabbro is worked at two quarries for use as roadstone and for armour stone; both quarries have seaborne access.

As the primary variations in basic igneous rocks are complex and may not be directly related to the perceived technical properties, no differentiation has been made on the Resource Map between intrusive and extrusive greenstones. In areas where the 1:10 560- and 1:10 000-scale mapping shows a multiplicity of small outcrops, those with a maximum width of < 100 m have been excluded. In some areas, larger bodies have been excluded for reasons of clarity. It must be emphasised that the basic igneous rocks depicted on the map show wide variations in properties, and, therefore, suitability for use. As with all the identified mineral resources, their potential can only be determined after detailed examination.

Serpentinite and Picrite

Outcrops of sepentinite and picrite (ultrabasic rocks with extremely high original Fe and Mg and low SiO_2) occur in the Lizard peninsula, and on a very restricted scale in east Cornwall. On the Lizard, local patches of serpentine are worked for carving stone and support a local industry manufacturing souvenirs. One quarry was, until recently, producing crushed rock aggregate. In east Cornwall, a serpentinised picrite at Polyphant, near Launceston, has been worked from at least Norman times as an ornamental stone ('Polyphant Stone') for carved work in churches and other buildings. Very minor quantities are still produced from time to time. The intrusion has been extensively altered and has, in the past, been investigated as a potential source of low-grade talc. However, the rock is too contaminated with iron oxides to be of economic interest.

[3] *Aggregate Abraison 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.*

SANDSTONE

Many of the sedimentary rock formations in Cornwall include considerable volumes of sandstone. In some cases sandstone is the dominant lithology in thick or massive beds. Elsewhere sandstone is interbedded with slate, shale or siltstone in very variable proportions, and only those areas with higher concentrations of sandstone beds are likely to be of potential. Examples of the first type are parts of the Late Carboniferous Bude Formation of north Cornwall and parts of the early Devonian Staddon Grit. The second type are exemplified by much of the late Carboniferous Crackington Formation of north Cornwall and the late Devonian Portscatho Formation. Most of the sandstones are technically ‘greywackes’, that is generally fine- or medium-grained sandstones, which, at the time of sedimentation included some silt and clay that acted as a fine matrix. Individual sandstones vary in thickness, lateral persistence, grain size and strength, the latter depending on the degree of metamorphism and state of weathering. All of these factors have a bearing on the physical properties and thus aggregate potential of the sandstones. Despite apparently extensive resources, relatively little sandstone is produced in the county, reflecting the relatively high cost of working and competition from igneous rock.

Many quarries, mostly of small size, are scattered throughout the sandstone outcrops of the county, and the material worked has found use as a local building stone and as roadstone. In some localities, very fine-grained, somewhat fissile, sandstone grading into very silty slate is worked for these purposes and may be referred to as sandstone or shale/slate.

Very few technical data are available for the sandstones of Cornwall. Some high-specification sandstones suitable for road surfacing occur in the late Carboniferous Culm Measures of north Cornwall. These have been shown to have considerable resistance to polishing (PSV > 60) and to wear (< 10 AAV). Sandstones within the Bude Formation are thicker than those within the Crackington Formation, but are considered to be more variable in quality. In both formations, the presence of interbedded shales reduces the opportunity for quarry development.

A broad-brush approach has been used to identify sandstone resources on the map. Those formations that have been depicted are known either to consist mainly of sandstone without detailed knowledge of the technical properties, or which are known to have potentially workable deposits of known quality within shale or slate sequences. However, the presence of interbedded shales significantly reduces the aggregate potential of such materials.

SLATE

In its most general usage, the term ‘slate’ is applied throughout Cornwall to the more or less fissile mudstones and siltstones that comprise the greatest volume of sedimentary rocks in the peninsula and is synonymous with the Cornish language term ‘killas’. Slate, in this broad sense, was, and continues to be, worked very widely, mostly from small quarries, for general building purposes such as stone walling, paving and general fill. Roughly dressed slate is popular for garden walls and rockery construction. The aspect and nature of these materials is very variable, with colour ranging from dark to light grey with green and red hues; brown iron oxide staining is commonly present, producing a ‘rustic’ effect, as also is quartz veining. The rock locally varies from true mudrock to fine sandstone and more-or-less fine laminations of more clay-rich and silt or sand-rich layers may be present (this is particularly a feature of the Mylor Slate Formation of west Cornwall).

Slate which can be readily split into thin sheets or slabs suitable for roofing and other architectural purposes, is of much more restricted occurrence. Such material depends on the occurrence of fine-grained rocks, such as mudstones, which have been affected by low-grade metamorphism resulting in the development of a well-marked slaty cleavage due to the crystallisation and realignment of platy minerals within the rock mass. It is along these cleavages that the rock can be split and thus giving it its economic importance. Bodies of such slate generally have a restricted occurrence within extensive masses of less perfectly cleaved material, which accounts for the large tips of waste material commonly associated with the slate industry.

Cornwall was, in the past, an important source of roofing slate mostly derived from the late Devonian strata of north Cornwall, and the slate belt immediately to the south of the Bodmin Moor Granite. The largest working, which continues in operation to the present day, is the giant quarry at Delabole, noted for its distinctive silvery grey slate. The quarry produces roofing slate, dimension stone and slate granules and powder for filler applications. Elsewhere, most of the operations are small quarries producing rustic slate for paving, cladding, walling and fireplaces.

The map shows areas where the strata are predominantly of slate in the more restricted definition of the term and which have, in the past, been locally worked for high quality material. Slate workings for general building material and fill exist in many other places, some of these are active at the present time, and here the slate is commonly interbedded with bodies of sandstone and siltstone.

SAND AND GRAVEL

Cornwall has very limited resources of natural sand and gravel. Small outcrops of Tertiary and Quaternary sediments, such as those at Crousa Downs on the Lizard, and around St. Agnes Head, have been worked, and the latter is also a source of pottery clay and sand for industrial use. The beach and dune sands of Cornwall's north-western coastline have been worked, mostly as an alkaline soil conditioner, due to their high content of shell debris. There is a small production of beach and dune sand near Hayle for construction use as building sand. There has also been some intermittent production of dredged estuarine sand in the Camel estuary.

A major secondary source of sand is china clay waste (see Secondary aggregates).

METALS AND RELATED MINERALS

Mineralisation

Most of Cornwall's metalliferous deposits occur as veins with a close spatial relationship to granite outcrops or to unexposed granite bodies present at shallow depth. Fluids escaping along fractures from the cooling granite bodies were responsible for depositing a wide range of minerals, including metal ores. This fluid movement was sustained and enhanced by the radiogenic heat produced by the decay of natural isotopes of thorium and potassium and, in particular, uranium. This led to a complex sequence of mineralising events, with individual veins or 'lodes' carrying particular assemblages of minerals.

There is a close geographical connection between the granites of Cornwall and the location of the important mining districts. The veins within and close to the granites mostly carry tin, in places, with tungsten and arsenic. In the rocks immediately around the granites, copper and arsenic may be found with tin, while further out, tin diminishes and zinc may be present. Veins carrying lead, silver and zinc, together with spar minerals such as fluorite and barite, are to be found at some distance from the granite outcrops; many of these veins trend north-south (referred to as cross-courses) in contrast to the predominant east-west trend of the tin-copper-arsenic structures. In some districts, as around Gunnislake, the veins are noted for their polymetallic character. This is the result of a number of mineralising events being superimposed in the same structure and can lead, for example, to tin, tungsten, arsenic, copper, zinc, and fluorite occurring together.

Certain horizons within the slate, sandstone and basic igneous rocks throughout Cornwall contain mineralised structures and are enriched in metals, including veins and stratiform deposits, that are unrelated to the granites and their thermal influence.

Tin

Cornwall and, to a lesser extent Devon, are the only areas in Britain where tin minerals have been produced in commercial quantities. Modern estimates suggest that Cornwall and Devon together may have produced between 2.5 and 3.0 million tonnes of tin metal (Sn). The earliest tin ore production was from river gravels and other surface deposits, while in more recent times, deep mining of veins has been of greater importance. This change reflected the exhaustion of the alluvial deposits in late medieval times and the introduction of technology that provided first for the construction of drainage levels ('adits') and, later, for mechanical pumping to facilitate deep mining operations.

Tin production peaked at some 10 000 tonnes tin metal-in-concentrate in 1870–71, but declined rapidly thereafter. A resurgence in Cornish tin production, principally following the commissioning of Wheal Jane in 1971, increased output to 5 200 tonnes tin-in-concentrate in 1984 and 1985. However, this level of output proved to be unsustainable in the face of low tin prices following the demise of the International Tin Council, resulting in the closure of all the tin mines except the South Crofty mine at Pool near Camborne. Wheal Jane, which closed in February 1991, was by far the largest of the closures and produced 1 041 tonnes tin-in-concentrate during its last full year of production. The South Crofty mine is operating to a depth of more than 800 m below the surface and has an annual production of about 2 000 tonnes of tin-in-concentrate. Reserves have been estimated at 830 000 tonnes of ore at 1.54 per cent Sn within a larger resource of 3.2 million tonnes at 1.50 per cent Sn. However, the closure of the South Crofty mine was announced in August 1997 bringing to an end the long history of tin mining in Cornwall.

The principal ore mineral of tin is cassiterite (SnO_2), which commonly occurs in veins combined with other minerals, such as quartz, tourmaline and chlorite, and also with other metal ores including base metals and iron sulphides, tungsten minerals and iron oxide in various forms. The separation of cassiterite (also known as 'black tin') from associated minerals involves crushing followed by hydraulic concentration. During these processes, associated minerals of iron and tungsten may be removed by magnetic separation, and sulphide minerals by flotation treatment.

The orebodies which contain tin are very variable in form and grade and typical veins vary in width along their lateral extent. Most of the larger mines worked substantial veins in which the ore grade lay between 1 and 2 per cent tin metal by weight. In some places, very rich pods of ore, known locally as 'carbonas', have been worked but these are generally of limited size. Of greater interest in the modern period has been the exploration of large-scale, low-grade orebodies which might be amenable to large volume extraction, either by openpit or deep mining, for example the tin-tungsten sheeted vein complexes at Cligga Head and Redmoor. Not all tin-bearing orebodies are veins; at various localities are beds of ore 'tin floors' in which cassiterite occurs in intimate association with silicates and, in some cases magnetite. Examples of these 'stratiform' tin deposits are Grylls Bunny at Botallack, near St. Just-in-Penwith and the Magdalen Mine, near Ponsanooth.

The British Geological Survey has undertaken mineral exploration activity in Cornwall, principally through the Mineral Reconnaissance Programme (MRP) funded by the Department of Trade and Industry (DTI). In addition, between 1972 and 1984 the DTI provided financial assistance to industry for mineral exploration in Great Britain through the Mineral Exploration and Investment Grants Act 1972 (MEG). A number of companies were active in Cornwall during this period. The Act required companies to deposit information from prospecting work with the BGS. Details of the relevant MRP an MEG open file reports for Cornwall are given in the bibliography.

Copper

In terms of historical production, copper was the second most important metal worked from the Cornish veins. It is probable that the total production has been in the region of 2 million tonnes of metal, though records are incomplete. There is little information about the production of copper in early times and systematic mining of the metal does not appear to have commenced before the 16th century. In the first half of the 19th century production increased considerably and more than 40 per cent of the world's output was obtained from Cornwall and Devon. The highest production was reached about 1860 with an annual output of more than 15 000 tonnes of metal. After this period the production declined dramatically and by the beginning of the 20th century the output was negligible. Small amounts of copper (up to 1 000 tonnes a year copper-in-concentrate) were formerly produced at Wheal Jane in a by-product zinc-copper concentrate.

The principal ore of copper is chalcopyrite ($CuFeS_2$). Other copper iron sulphides, such as bornite (Cu_5FeS_4) and also the copper sulphide chalcocite (Cu_2S), also occur. Carbonates, oxides and native copper have also been found in the upper parts of veins. Copper occurs together with tin and arsenic in many districts and the waste minerals in the veins are most commonly quartz with tourmaline, chlorite, fluorite and carbonates. It is not uncommon for veins situated close to the boundaries of granite bodies to have a copper-tin-arsenic association, while those farther into the country rock contain copper with zinc. Small tonnages of copper ores have in places been worked from lead-zinc-silver veins.

In the past copper ores were concentrated by hand picking of the coarser material and gravity separation of the finer fractions. In the present century, the small production of copper has mostly involved flotation, and this process has been used to remove traces of copper and other sulphides from the tin ores. At a number of localities, copper has been produced by precipitation on scrap iron using either copper rich mine drainage waters or leachate from dumps and low-grade tailings.

Tungsten

Tungsten ores were formerly regarded as an impurity in tin concentrates and, until the middle of the 19th century, were treated as waste. After the recognition of the properties of tungsten metal as an additive to alloys and steel, there was a demand for tungsten resulting in production from a number of Cornish mines. Dines (1956) records a fluctuating output between 1910 and 1934, and a steady production of about 200 tonnes of concentrates per annum thereafter, up to the closure of the main producer, Castle-an-Dinas Mine in 1958. A minor production has been recorded in more recent years, but there is no production at present.

Tungsten ores occur at many localities in Cornwall, normally in vein deposits, and commonly in association with tin. The tungsten-bearing ore bodies are generally within, or very close to, outcrops of granite, and are often enclosed by a distinctive alteration product of granite ‘greisen’ in which original granite is replaced by a dark grey mass of mica and quartz. At several localities, for example at Cligga Head or St. Michael’s Mount, tungsten ores occur in sheeted (i.e. multiple and parallel) vein complexes, while elsewhere, as in the Gunnislake district, the ores may be found in fissure veins.

The principal ore of tungsten is the iron/manganese tungstate, wolframite. Calcium tungstate, or scheelite, also occurs but is not important as an ore mineral in Cornwall. Wolframite occurs in veins together with quartz; some cassiterite may also be present in variable proportions. Small amounts of sulphides and arsenic minerals also occur in tungsten veins, but are usually minor.

Arsenic

In the early years of Cornwall’s mining history, arsenic minerals were regarded as an undesirable waste material in the tin and copper lodes. Just before 1870 a demand for arsenic in the chemical industry led to the extraction and refining of arsenic as a by-product at a number of Cornish mines. In the latter years of the 19th century it is stated that a relatively small number of mines around Callington in east Cornwall and Tavistock in west Devon were producing about half of the world’s output (Dines, 1956). Much of the refined arsenic was used in the production of insecticides to combat the American Boll Weevil. Between 1870 and 1900 the annual output of arsenic oxide varied between 4 000 and 8 000 tonnes. Subsequently production declined to less than 2000 tonnes per year after 1920 and ceased altogether in 1938.

The principal arsenic mineral is arsenopyrite ($FeAsS$) also known as mispickel or ‘white mundic’. Arsenic also occurs in lollingite ($FeAs_2$) and in other sulphides and secondary arsenates. As noted above, it occurs in veins together with tin and copper minerals, also in minor amounts with lead, zinc and antimony ores.

In the past some mines sold arsenic ores in the natural state but it was more usual for the material to be roasted (calcined) and the resulting vapours passed through flues where arsenic oxide precipitated as a grey sooty powder. This arsenic soot, containing 80–90 per cent of arsenious oxide was the form in which the material was usually sold, but at some mines refined arsenic containing 99.5 per cent of the oxide was produced and the roasted ores were treated to remove any tin and copper that may have been present. The production of arsenic from the mines of Cornwall has left a considerable legacy of pollution stemming from waste dumps and from the effects of former refining operations.

Zinc

Until the early 19th century zinc ores were commonly discarded, as there was only a limited market for zinc in the production of brass. Subsequently zinc concentrates were produced, with a peak between 1850 and 1885, much of it from veins in the St Agnes district. In recent years zinc concentrates have been produced from the polymetallic ores at Wheal Jane; prior to its closure in 1991, some 5 500 tonnes of zinc-in-concentrates were produced annually.

The principal ore of zinc is the sulphide sphalerite (ZnS), also known as blende or ‘black jack’. Other zinc minerals such as the carbonate calamine also occur but only in minor amounts. Sphalerite occurs in association with lead and copper ores and is particularly common in north–south veins. Impurities in zinc ores include lead and the very toxic element cadmium. Cadmium anomalies may occur around sites of former zinc mining or the treatment of its ores.

Lead

Lead mining has a long history in Cornwall and, at the eastern boundary of the county, the Bere Alston mines were known to have been active in the 13th century. There is little information about output prior to the beginning of the 19th century, at which time the annual output increased to over 10 000 tonnes of ore between 1845 and 1850. After 1850 production declined and ceased completely in 1877, since when production has been spasmodic and very small. Dines (1956) states that between 1845 and 1886, 255 968 tonnes of lead ore were raised in Cornwall. The metallic content of lead concentrates was commonly between 60 and 75 per cent.

The principal ore mineral of lead is the sulphide galena (PbS); other minerals containing lead include the carbonate, cerussite, and a phosphate, pyromorphite, but these are of minor importance. Galena occurs in veins together with sphalerite and other sulphides including silver minerals. Quartz, fluorite, barite and carbonates in various combinations commonly accompany the metal sulphides. The lead-bearing veins are commonly of north–south trend; these are termed cross-courses. Lead also occurs in veins of east–west trend as in the Chiverton mines of the St Agnes area.

Silver

Lead ores from Cornwall may contain varying amounts of silver ranging up to 180 oz per ton of lead metal. The silver is present as mineral inclusions in galena and as small individual concentrations of silver minerals, commonly sulphides. The silver present in lead ores has been the main source of that metal in South-west England but there has also been production from copper and zinc concentrates and also from true silver ores containing minerals such as native silver, pyrargyrite and rare silver chloride minerals such as cerargyrite. The copper-antimony sulphide, tetrahedrite, also contains silver. The occurrence of silver is as for lead above, in addition there is a common association with the ores of bismuth, cobalt, nickel and antimony. There are sparse records of early production of silver from Cornwall; the bulk of production was during the 19th century. The zinc-copper concentrates formerly produced at Wheal Jane contained modest amounts of silver.

Iron

Significant quantities of various iron ores have been raised in Cornwall. The occurrences are mostly veins but there are also stratiform ore bodies of several kinds including iron-rich skarns. Most of the ores produced were of iron oxides and hydroxides, these usually representing weathered primary ore such as siderite (iron carbonate) and pyrite (iron sulphide). Small amounts of magnetite have also been worked.

Most of the iron ores raised in Cornwall were sent for smelting but some (see below) were worked for use as mineral pigments. Cornwall’s production of iron ore has not been fully recorded; a recent estimate suggests that during the 19th Century about 1 000 000 tonnes were sold.

Uranium

Small amounts of uranium ores have been encountered from time to time in the workings of a number of Cornish mines and in the 19th century, from 1845 onwards, there was some sale of uranium ores mostly for use as a glass colourant and for the production of ceramic glazes. Dines indicates that the total output of uranium ores for the region probably does not exceed 2 000 tonnes. Uranium is mostly commonly encountered in the form of its oxide, pitchblende and the secondary minerals autunite and torbernite. Uranium minerals occur mainly in cross-courses with low temperature minerals such as those of iron, cobalt, nickel and bismuth.

There has been no production of fissile material from the local veins, and a resource assessment undertaken by the UKAEA after World War II demonstrated very small resources.

Gold

Gold has been recovered from many alluvial tin workings in Cornwall, but the amounts produced were very small and have mostly not been recorded. Gold is also present in the antimony ores of north Cornwall, notably at Treore mine, where gold trials were made in the alluvium below the mine in the early 1900s. Dines (1956) notes that 4 oz gold were recovered from copper ores at Levant mine, and other tin and copper mines recorded gold occurrences, usually in the weathered zones or 'gossans' above the main lodes.

In recent years work carried out by the Mineral Reconnaissance Programme has identified traces of gold in Middle Devonian to Lower Carboniferous rocks of east and north Cornwall. These have attracted commercial interest and exploration is continuing under licences granted by the Crown Estate.

Other metals

Antimony, bismuth, cobalt, manganese and nickel minerals occur in minor amounts at a number of localities and have been produced on a small scale in the past. Molybdenum occurs as the sulphide molybdenite at several localities, and there was a small production from Drakewalls mine near Callington.

Metals in the future

Given a sufficient increase in metal prices there would undoubtedly be further interest in Cornwall's metal ores and particularly in locating large tonnage tin or tin/tungsten deposits. Other targets might include complex polymetallic deposits requiring advanced processing technology to achieve effective separation of the component minerals containing elevated levels of precious metals. As noted above, there is current interest in gold and related mineralisation in the rocks of east Cornwall.

Spar minerals

Fluorite or fluorspar (calcium fluoride) occurs in many veins in Cornwall, mostly in association with the ores of lead and copper. Output has not been accurately recorded but the region has never been a significant producer. Recent proposals to recovery small amounts of fluorspar at the South Crofty mine have not come to fruition.

Barytes (barium sulphate) was formerly worked from mines in the Teign Valley area of Devon, but the small occurrences in Cornwall have never been exploited.

Mineral pigments

Ochre and umber are earthy mixtures of hydrated iron oxide minerals with clay, with, in the case of umber, a certain proportion of manganese oxide minerals. Ochre and umber have been worked in a number of localities in South-west England, either from the weathered parts of veins (gossans) or from weathered and altered bodies of greenstone or limestone. At some localities, the finely divided iron oxide minerals which collect in adit drainage waters have been used as a form of ochre. Before the modern period these materials were widely used as colourants in many applications.

Lithium

The St. Austell Granite hosts a considerable, although low-grade, lithium resource which is present in lithium-bearing micas containing up to 2.5 per cent lithium metal. Present day needs are mostly met from overseas high-grade deposits and it is unlikely that this occurrence will be of economic interest in the foreseeable future.

ENERGY RESOURCES

Geothermal energy

Cornish granites are characterised by a high content of radiogenic elements (U and Th) and have an anomalously high heat output compared with the surrounding rocks. An extensive research programme and pilot project to assess the potential of obtaining geothermal energy from Cornish granite has been carried out at the Rosemanowas quarry, near Camborne. However, this energy source is not currently economically viable.

Oil and gas

Cornwall has no conventional hydrocarbon or coalbed methane potential.

SECONDARY AGGREGATES

The term 'secondary aggregates' is used to describe a range of natural and manufactured wastes that may find application as an alternative to primary aggregates. Cornwall has very large resources of secondary aggregates, by far the most extensive being china clay waste (sand and rock).

China clay waste

The extraction and processing of china clay involves the production of very large quantities of waste. Each tonne of china clay recovered typically produces 9 tonnes of waste, comprising 4 tonnes of granular waste (china clay sand), 2.5 tonnes of rock waste ('stent'), 1.5 tonnes of overburden and 1 tonne of micaceous residues. Total industry arisings are some 27 million tonnes a year, of which some 12 million tonnes is china clay sand, the bulk of which is produced in Cornwall. The total industry stockpile has been estimated at over 600 million tonnes, with over 430 million tonnes occurring in the western and central parts of the St Austell Granite (Whitbread and others, 1992), although many waste tips have now been restored. Rock waste and sand are generally tipped separately.

China clay waste is used fairly extensively in Cornwall as a construction raw material. Total usage is about 1.5 million tonnes a year, of which approximately two-thirds is sand and the remaining third crushed igneous rock ('stent'). This output is recorded with primary aggregates output in official statistics. A major end use is the manufacture of concrete blocks, but other uses include road sub-base, structural concrete and building sand. There are technical constraints on the use of the sand, including poor workability and a higher cement requirement to achieve adequate strengths. However, transport costs remain the major constraint on the use of china clay waste in more distant markets.

A study on the landscaping and revegetation of china clay wastes has been undertaken as part of the DOE's Geological and Mineral Planning Research Programme (Wardell Armstrong, 1993).

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. Today, producers try to convert as much of the extracted mineral as possible into a saleable form. Crushed and graded slate waste can be used for construction purposes, such as Type 1 and Type 2 sub-base, larger blocks can be used for armour stone, smaller blocks for rip rap, and also 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 and landfilling. However, the low price of the material usually restricts its use to the vicinity of production.

The Delabole slate quarry in north Cornwall is the only significant source of slate waste in the county. The associated tip contains some 10 million tonnes of slate waste and overburden mixed in roughly equal proportions, but is effectively sterilised by the surface processing facilities and restoration conditions. The only material available for possible use as a secondary aggregate, mainly as bulk fill, is the waste generated during slate quarrying, and amounting to some 50 000 tonnes/y. Quarry waste is tipped in the quarry, but waste arising from processing is all sold in some form, including as slate powders and granules. Elsewhere in Cornwall, slate waste has traditionally been used for field walls.

Metalliferous mining sites

There is now only one operating metal mine in Cornwall, but spoil heaps from former metal mining operations are widespread. Although these have been worked for construction use in the past, they have a variable composition and some may pose a potential risk of pollution to the wider environment if disturbed or used as sources of secondary aggregates. (Environmental Consultancy University of Sheffield and others, 1994). The manufacture of concrete blocks with certain types of mine waste containing sulphides has created a serious problem due to the oxidation and the formation of sulphuric acid which has attacked the concrete with serious consequences.

At South Crofty mine, granite produced during mine development may be disposed of underground, but some is brought to the surface and crushed for use as roadbase material.

MINERAL RESOURCES AND PLANNING CONSTRAINTS

The character of the landscape 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. It is constantly changing, due in the longer term to geomorphological processes and, in the shorter term, to economic and social pressures. Mineral extraction can cause irrecoverable, but not necessarily harmful, change to a locality over a relatively short timescale. In order to ensure that such changes are both sustainable and non-injurious to the environment, the most valuable landscapes and habitats, such as AONBs and SSSIs, are given a greater degree of protection from mineral working. The need for mineral workings in such areas has to be justified by a most rigorous examination of the merits of the proposal. This examination should consider the public interest in the development of the resource, including the social desirability of the employment it will create, as well as the need to protect the environment.

Minerals extraction in areas proposed as SPA or SAC sites may be acceptable if there are no alternatives and if there are imperative reasons for the development which are of overriding public interest. For certain priority sites, development can only be considered to be acceptable due to overriding reasons of public health and safety or beneficial environmental consequences.

The resolution of conflicts between mineral resource development and other considerations is undertaken through the development plan framework and a balanced appraisal of the various issues associated with the development. The Mineral Resources Map of Cornwall provides a synthesis of available information which can be revised and updated as additional data becomes available. In addition, additional constraint information can be incorporated as required. It is hoped that the map and the associated concise report, will assist local and national Government, the minerals industry and other interests in the consideration and production of policies included in development plans.

Large parts of Cornwall are covered by national planning designations. The Cornwall AONB is fragmented, but covers a total area of 957 km^2. It contains some of Britain’s finest coastal scenery, including Land’s End and the Lizard peninsula, and tracts of the northern and southern coasts, which are also, in part, coincident with ten stretches of Heritage Coast. The coastline, both inside and outside the AONB, is subject to a number of SSSI designations relating to cliffs and dunes. Cornwall is an exceptional area for the study of metalliferous and vein minerals and this is reflected in the range of SSSIs which include both minerals in their original locations and some mine dumps.

There is a noticeable relationship between the extent of national planning designations and particular resource areas. Three areas of significant importance in planning terms, but which also have several mineral workings, are the granite masses of Bodmin Moor and Land’s End, and the Lizard Complex. These areas are either wholly, or mainly, designated as part of the AONB, contain a concentration of scheduled monuments and also have extensive areas of SSSIs, relating mainly to lowland heath and moorland. Extensive NNRs occur on the Lizard peninsula. In contrast, the St Austell and Carnmanellis granites have few planning designations.

There are few SSSIs outside the above areas with the notable exception of the SSSI/NNR at Goss Moor, north of the St Austell Granite. There are no other significant numbers of scheduled monuments except for those along the sandstone outcrop between Trenance-Bodmin-Liskeard.

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

Planning Policy Guidance
Mineral Planning Guidance Notes
Regional Planning Guidance Notes

a) British Geological Survey 1:50 000 or 1:63 360* scale New Series geological map sheets

In 1835-1839, Henry De la Beche produced a set of one-inch scale geological maps of Cornwall, and these, together with a slightly earlier survey of Devon, were the first government-funded Geological Survey maps of the UK landmass. A six-inch scale geological survey was carried out in the last years of the 19th century and the early decades of the 20th; at the present time revision 1:10 000-scale mapping is in progress. At all stages the published maps have been accompanied by explanatory reports and memoirs. A landmark in the Geological Survey's work in Cornwall was the publication, in 1956, of the memoir `The metalliferous mining region of south-west England' by H G Dines.

Information from the following documents and maps was used in the compilation of the map.

Sheet	name	surveyed/ latest revision	published
307/308	Bude	1963–73	1980
322*	Boscastle	1963–64	1969
323	Holsworthy	1963–66	1974
335/336	Trevose Head & Camelford	1986–90	1994
337	Tavistock	1978–81	1993
346	Newquay	1906	1981
347	Bodmin	1900-06	1982
348[a]	Plymouth	1907	1977
352	Falmouth	1980–84	1990
353/354	Mevagissey	1907	1975
351/358	Penzance	1970-76	1984
359	Lizard	1934	1975

[a] A new Plymouth sheet (348) is in press.

b) British Geological Survey Sheet Memoirs

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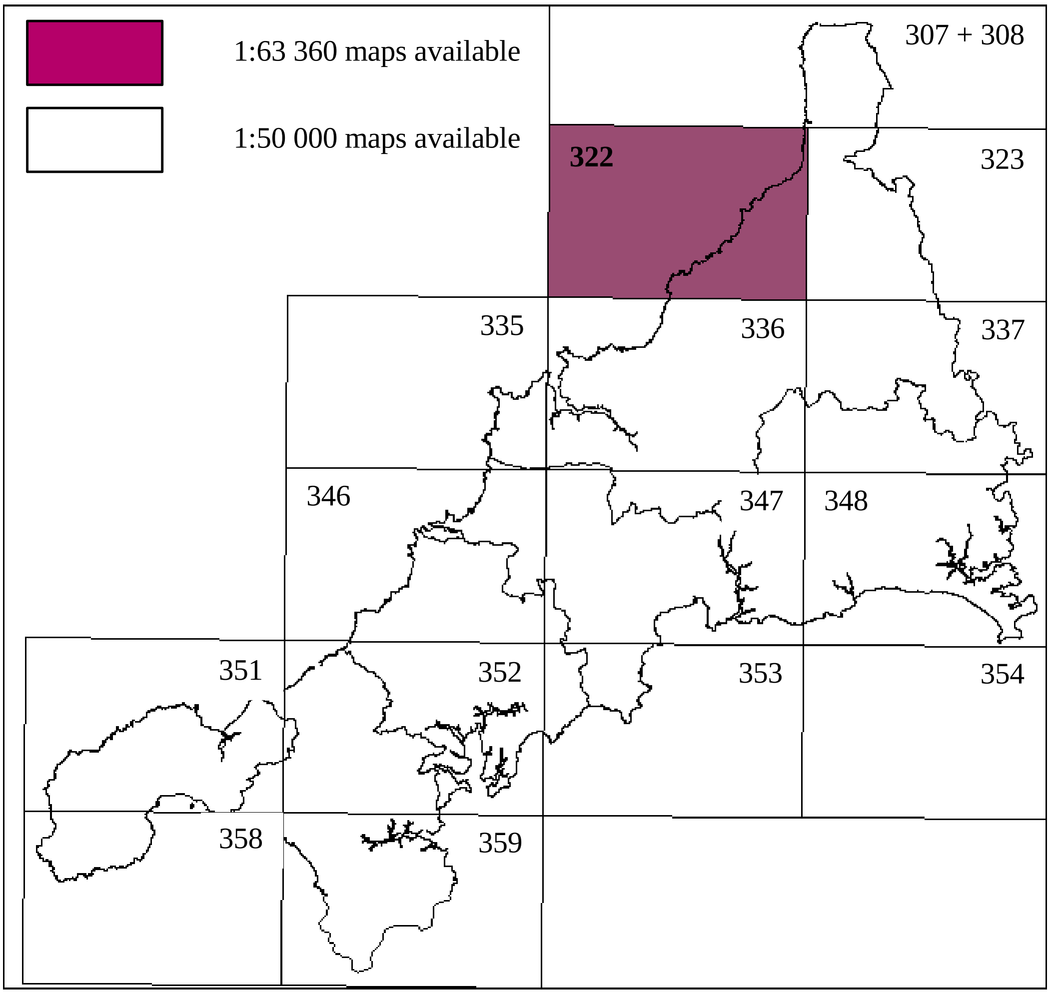

Figure 5 Availability of British Geological Survey 1:50 000 or 1:63 360 scale New Series geological map coverage of Cornwall

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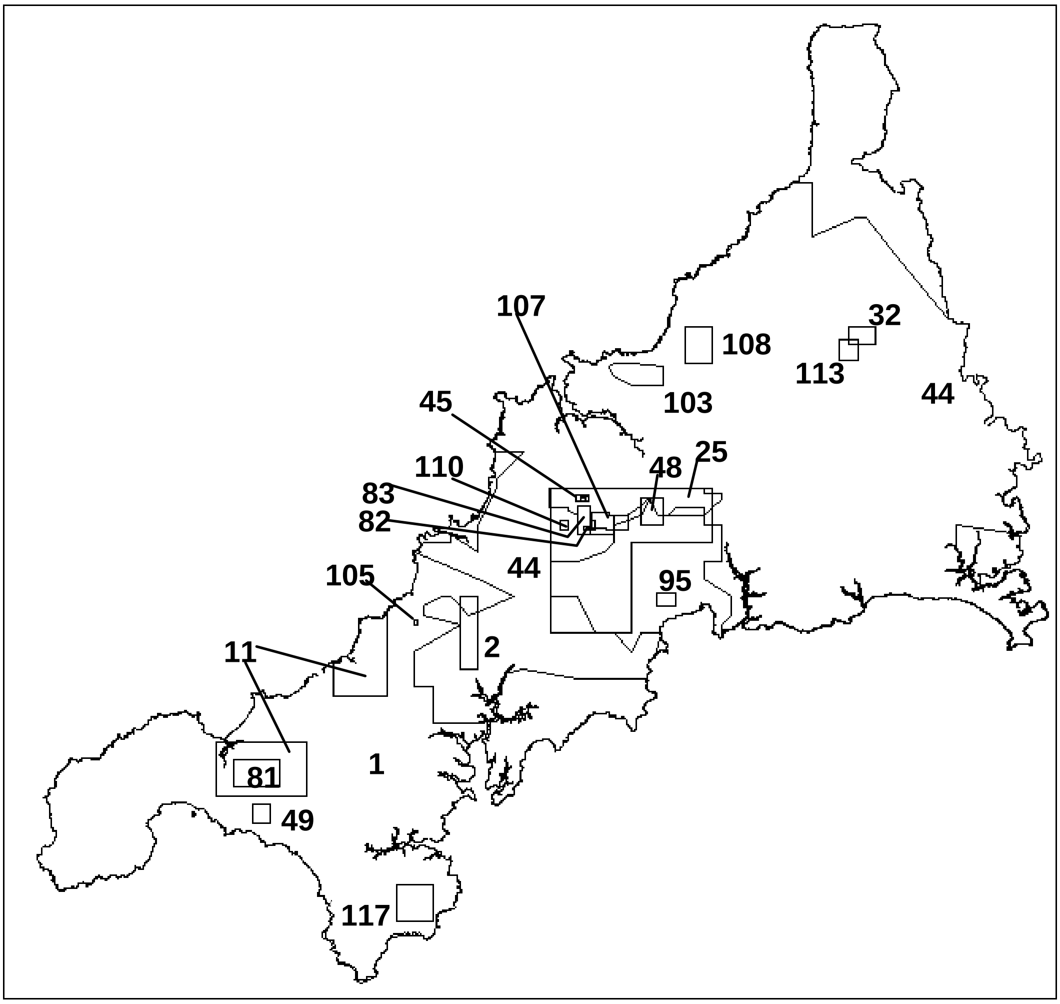

Figure 6 Location of MRP areas in Cornwall

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39	Cligga Head	Int. Mine Services	tin, tungsten
40	Blue Hills	Int. Mine Services	tin, copper
42	Nancegollen	Jewill Hill & Associates	tin
50	Tolgus Tunnel	South Crofty Ltd	tin
64	St Ives Bay	Marine Mining Corporation	tin
65	Godolphin Tin	Thyssen GB Ltd	tin
73	Mulberry	Noranda Kerr Ltd	copper, tin
106	Elfordleigh	Consolidated Goldfields Ltd	tin, tungsten
118	Hawkmoor/Bedford United	Continental Ore Co Ltd	tin, tungsten
119	Duchy Peru	Texas Gulf Anglo Exploration Ltd	copper, lead, zinc
129	Chacewater	Consolidated Goldfields Ltd	tin
159	Castle-an-Dinas	St Piran Exploration	tin, tungsten
161	Killivose	Great Western Ores	tin
162	Bedford United/Ding Dong	South West Consolidated Minerals Ltd	tin
163	Trenery's Prospect	Cornwall Tin & Mining Ltd	tin
164	Silver Valley	South West Consolidated Minerals Ltd	tin
165	Redmoor	South West Consolidated Minerals Ltd	tin
177	Killivose Tunnel	Great Western Ores Ltd	tin
178	Restronguet Creek	Billiton Minerals	tin
180	Killivose North Branch	Great Western Ores Ltd	tin
182	Breney/Redmoor	Consolidated Goldfields Ltd	tin
184	Killivose DDH 136	Great Western Ores Ltd	tin
185	Trewint and Tregirls	Hemerdon Mining & Smelting Ltd	tin
188	Goonzion Downs	Geevor Tin Mines Plc	tin
190	517 Watertight Door	Great Western Ores Ltd	tin
191	Reeves Lode	South Crofty Ltd	tin
195	Dolcoath South Lode	South Crofty Ltd	tin
196	Roskear Complex Lode	South Crofty Ltd	tin
198	Mulberry	Central Mining Finance Ltd	tin, tungsten
200	Level 9, Wethered Lode	Geevor Tin Mines Plc	tin
201	West Stray Park, DD 43	Great Western Ores	tin
202	Allen's Shaft	Geevor Tin Mines Plc	tin
203	Dolcoath Branch & Mine	South Crofty Ltd	tin
208	Wheal Concord	Wheal Concord Ltd	tin, tungsten
210	Goss Moor	Billiton (UK) Ltd	tin
211	Withey Brook Marsh	Geevor Tin Mines Plc	tin
212	Haye South	Amax Hemerdon Ltd	tin, silver, lead
213	Cligga	Amax Hemerdon Ltd	tin, tungsten
214	Whiddon Down	Amax Hemerdon Ltd	copper, tin, lead
216	Trevince Estate	Cornwall Tin and Mining Services Ltd	tin
218	Gonamena	Black Rock Mineral Ventures Ltd	tin, tungsten
222	Offshore Tin Alluvials	Billiton (UK) Ltd	tin

223	Egloskerry	Riofinex	lead, zinc
224	Prince of Wales	Brampton Resources Ltd	tin, tungsten, copper
225	Remote Sensing	Billiton (UK) Ltd	tin, tungsten, lead
228	Great Wheal Carne	Geevor Tin Mines Plc	tin
231	6 Level Exploration	Great Western Ores Ltd	tin
232	Tregullan	Central Mining Finance Ltd	tin, copper, tungsten
235	Bridestowe	Riofinex	copper, lead, zinc
237	Fraddon Downs III	Billiton (UK) Ltd	tin, tungsten
239	Trelow Downs	Selection Trust	tin
245	Treliver 3	Billiton (UK) Ltd	tin
247	Great Flat Lode West	Great Western Ores Ltd	tin
251	Kellybray	South West Consolidated Minerals Ltd	copper, tin
255	Trewint	South West Consolidated Minerals Ltd	tin
256	Silverhill	South West Consolidated Minerals Ltd	tin
264	Offshore Spectrometric	Geevor Tin Mines Plc	tin
266	Dolcoath West Extension	Great Western Ores Ltd	tin

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ACKNOWLEDGEMENTS

This study has greatly benefitted from the co-operation of many organisations and individuals who provided information and advice, and their assistance is gratefully acknowledged. Particular thanks are due to the Department of the Environment, Transport and the Regions, Cornwall County Council, ECC International Europe, Goonvean Ltd, Bardon Aggregates, English Heritage and English Nature.

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APPENDIX 1 Mineral workings in Cornwall (1997)

Working	***Location***	***Operator***
China Clay		
Blackpool	St. Austell	ECC International Europe
Carclaze	Penwithick	ECC International Europe
Dorothy	Whitemoor	ECC International Europe
Goonbarrow	Bugle	ECC International Europe
Great Longstone	Whitemoor	ECC International Europe
Gunheath	Carthew	ECC International Europe
Littlejohns	Whitemoor	ECC International Europe
Longstone	Nanpean	ECC International Europe
Melbur	St Stephen	ECC International Europe
Park	St Neot	ECC International Europe
Penhale	St Austell	ECC International Europe
Rocks	Bugle	ECC International Europe
Stannon	Camelford	ECC International Europe
Treviscoe	Treviscoe	ECC International Europe
Virginia	St Stephen	ECC International Europe
Wheal Martyn	Carthew	ECC International Europe
Wheal Remfry	Fraddon	ECC International Europe
Bodelva	St Blazey	Goonvean Ltd
Goonvean Pit	St Stephen	Goonvean Ltd
Greensplat	St Stephen	Goonvean Ltd
Gt Wheal Prosper (Clay)	Roche	Goonvean Ltd
Rostowrack	Nanpean	Goonvean Ltd
China Stone		
Gt Wheal Prosper	Nanpean	Goonvean Ltd
Igneous Rock		
Bearah Tor	North Hill	I C Piper
Blackhill	Lewannick	Roseland Aggregates Ltd
Caradon (Gonamena)	Minions	Roseland Plant Ltd
Carnsew	Longdowns	Carnsew Quarries Ltd
Castle-an-Dinas	Penzance	Castle Granite Ltd
Chywoon	Penryn	C Lawer
Darley Ford	Upton Cross	Dilworth
Dean	St.Keverne	Redland Aggregates Ltd
De Lank	St Breward	Natural Stone Products Ltd
Goldiggings	Minions	Roseland Plant Ltd
Greystone	Lezant	Aggregate Industries PLC
Hantergantick	St Breward	Natural Stone Products Ltd
Hingston Down	Gunnislake	ARC - Southern
Kessel Downs	Longdowns	Aggregate Industries PLC
Luxulyan	Bodmin	Aggregate Industries PLC
Lean	Liskeard	Roseland Aggregates Ltd
Trannack	Coverack Bridges	E R Pascoe
West of England	Porthoustock	Seastop Ltd

Igneous rock is also produced as a by-product of some china clay operations.

Sand		
Gwithian Sandworkings	Hayle	ARC - Southern
New Downs Sand & Clay	St. Agnes	W Doble

Sand is also produced as a by-product of some china clay operations.

APPENDIX 1 continued:

Working	*Location*	*Operator*
Sandstone/Shale		
Cansford	Otterham	Messrs J Kingdon and G Wood
Pigsdon	Bude	Penhill Quarry and Haulage Ltd
Grampound (Treddinnick)	Grampound	Tredinnick Quarries Ltd
Pilsamoor	Egloskerry	M Symonds
Serpentine		
Ornamental Serpentine Workings (Lizard)	Lizard	R Hendy
Slate		
Callywith	Bodmin	J H L Stephens
Cannalidgey Farm	St Issey	A B Old
Clinnick Downs (Viaduct)	Broadoak	Mr S Bettison
Delabole	St Teath	Delabole Slate Co Ltd
James Park (Trago Farm)	East Taphouse	R Simmons
Lamparrow Stone Quarry	Tregony	F J Warne & Sons
Lantoom	Liskeard	Lantoom Quarry Co
Merryfield	Delabole	Mr E J Hillson
Pendarves Farm	Tregony	K H B Bullen
Prince of Wales Quarry	Tintagel	Realstone Ltd
Trecarne Quarry	Delabole	Mr R Uglow
Trevillett	Tintagel	Mill Hill Quarries Ltd
Tynes	Delabole	Mr E J Hillson
Tynes Middle	Delabole	Mr E J Hillson
Tredinnick Downs	Padstow	R A Jonas
Westwood	East Taphouse	Lantoom Quarry Co
Tin		
South Crofty Mine	Pool, Redruth	South Crofty Plc

APPENDIX 2 Contact addresses for further enquiries

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North Cornwall District Council Offices Higher Trenant Road Wadebridge Cornwall PL27 6TW Tel: 01208 812255 Fax: 01208 893255	Penwith District Council Council Offices St Clare Penzance Cornwall TR18 3QW Tel: 01736 62341 Fax: 01736 64292
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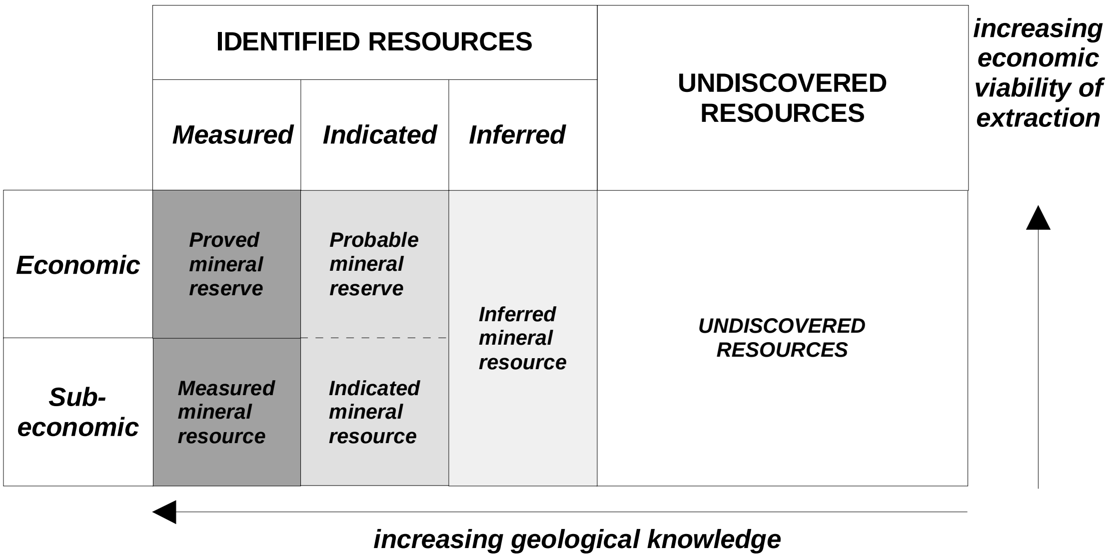
APPENDIX 3 Methodology

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 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.

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 on request.

Figure 1 Classification of resources



Based on McKelvey, 1972

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 it 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. Data on china clay resources was kindly made available by the china clay industry. 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. With respect to china clay, more comprehensive information on the distribution of resources has kindly been made available by the china clay industry. Within the present production areas of the St Austell Granite and the Bodmin Moor Granite, where the industry has carried out detailed evaluation work, the extent of **measured and indicated resources** is shown. These two categories have been combined to denote that systematic evaluation, including detailed quarry design, has been undertaken to different degrees of detail.

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 minerals extraction. That part of a resource that is both ‘measured’ and ‘economic’, i.e. it has been fully evaluated and is commercially viable to work, is called a **reserve** or **mineral reserve**. It is customary to distinguish between **proved** and **probable reserves,** which correspond to the economic parts of measured and indicated resources respectively (Figure 1).

In the context of land-use planning, however, 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 is shown on the Mineral Resources Map. 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 most 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 (DOE, MPG6):

- 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 Cornwall are shown on the map. The information is derived from the British Geological Survey’s Mines and Quarries Database, updated as appropriate from Cornwall County Council’s records. Letters (e.g. **Ig =** Igneous rock) are used to show the main mineral commodity produced.

The mineral planning permissions shown on the Mineral Resources Map were kindly made available by Cornwall County Council. They 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, included inactive sites, where the permission has expired due to the terms of the permission, i.e. a time limit, and inactive sites where permission still exists. Sites which have been restored are not separately identified. Information on the precise status and extent of individual planning permissions should be sought from Cornwall County Council.

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:

- some old permissions may be for minerals which are no longer of major economic importance and no resource has, therefore, been mapped

- 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 waste tipping

- isolated workings occurring outside defined resource areas may reflect very local or specific situations not applicable to the full extent of the underlying rock type.

- underground planning permissions for metalliferous minerals, mainly tin, cover extensive areas. The location of individual veins is not shown.

The latest data available for the total areas of planning permissions in Cornwall, 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 Cornwall (as at 1.4.94)

	Commodity	Total permitted area (ha)	No. of sites	%
Surface workings				
	China clay	1590	45	65.78
	Igneous rock	383	48	15.84
	Sand and gravel (construction)	113	5	4.68
	Sandstone	8	1	0.33
	Slate	166	31	6.87
	Vein minerals	130	21	5.38
	Other minerals	27	3	1.12
	total	**2417**	**154**	**100**
Underground workings				
	Vein minerals	3777	8	100
	total	**3777**	**8**	**100**

Source: *Department of the Environment, Survey of Land for Mineral Working in England, 1994. (London: HMSO, 1996)*