Mineral Resources
Consultative Committee

Mineral Dossier No 23

Limestone & Dolomite

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London
Her Majesty's Stationery Office

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PREFACE

The Mineral Resources Consultative Committee consisted of representatives of interested Government Departments, and specialist advisers. It was set up in 1967 to keep present and future requirements for minerals under review and to identify problems associated with the availability, exploitation and use of mineral resources, both inland and offshore, having regard to competing demands on land use and other relevant factors.

Widespread and increasing interest in the mineral resources of the United Kingdom led the Committee to undertake the collation of the factual information available about those minerals (other than fossil fuels) which were being worked or which might be worked in this country. The Committee produced a series of dossiers, each of which was circulated in draft to the relevant sectors of the minerals industry. They bring together in a convenient form, in respect of each of the minerals, data which had previously been scattered and not always readily available. These dossiers in updated form are now being published for general information.

ACKNOWLEDGEMENTS

The author wishes to record his thanks for the many contributions received during the preparation of this report. He is indebted to his colleagues at the Institute of Geological Sciences, in particular to Mrs W Khosla for work on the illustrations, to the staff of the Minerals Strategy and Economics Research Unit and to the many industrial companies who provided valuable information.

Metric units are employed throughout this document except where otherwise stated. In most cases this has necessitated the conversion of originally non-metric data. The units and conversion factors used are as follows:

millimetres	(mm)	=	inches x 25.4
metres	(m)	=	feet x 0.3048
kilometres	(km)	=	miles x 1.609344
hectares	(ha)	=	acres x 0.404686
kilogrammes	(kg)	=	pounds x 0.45359237
tonnes (1000 kg)		=	long tons x 1.01605

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SUMMARY

Limestone is a sedimentary rock composed mainly of calcium carbonate while dolomite is composed mainly of calcium magnesium carbonate.

Limestones are fairly widespread in the United Kingdom, except in Scotland, but exploitation is concentrated on Carboniferous limestones which occur mainly in Derbyshire, The Mendips, Gloucestershire, North Yorkshire, Cumbria, North Wales, South Wales and Northern Ireland. The Permian limestone, which outcrops between Newcastle and Nottingham, is also of importance and Cretaceous limestone (chalk) is used extensively in cement making. Total production from all other limestones accounts for only 10 per cent of United Kingdom output. Dolomite is produced mainly from the Permian and from the Carboniferous in South Wales, Gloucestershire and Shropshire.

Limestone is used in the construction industry principally as an aggregate and in the manufacture of cement. It is also used, either as the carbonate or as lime (CaO), in agriculture, in the steel, glass and chemical industries, in water treatment, building materials and in a wide range of industrial powders. Dolomite is used as an aggregate, in agriculture, in the manufacture of refractories, as a flux and in glass making. Both limestone and dolomite are used as building stone.

In 1979 16.3 million tonnes of chalk and 92.2 million tonnes of limestone, including 2.9 million tonnes of dolomite used for non-aggregate purposes, were produced in the United Kingdom. Limestone is the preferred source of roadstone, 35 million tonnes being used in 1979; it is the main raw material for the cement industry, which consumed 10.5 million tonnes of limestone and 13.3 million tonnes of chalk in 1979; it is basic to agriculture, which used 2.6 million tonnes of limestone and chalk in 1979 together with some dolomite; it is also a fundamental raw material in many industrial processes, which together consumed 10 million tonnes of limestone and chalk in 1979. Hence limestone and dolomite provide basic, high volume, cheap raw materials for which, in most cases, there are no practical substitutes.

Limestone and dolomite is usually exploited in large open quarries of up to 5 million tonnes annual capacity, which are difficult to locate unobtrusively in the attractive countryside often associated with limestone outcrops. Hence environmental factors are a major constraint on the industry.

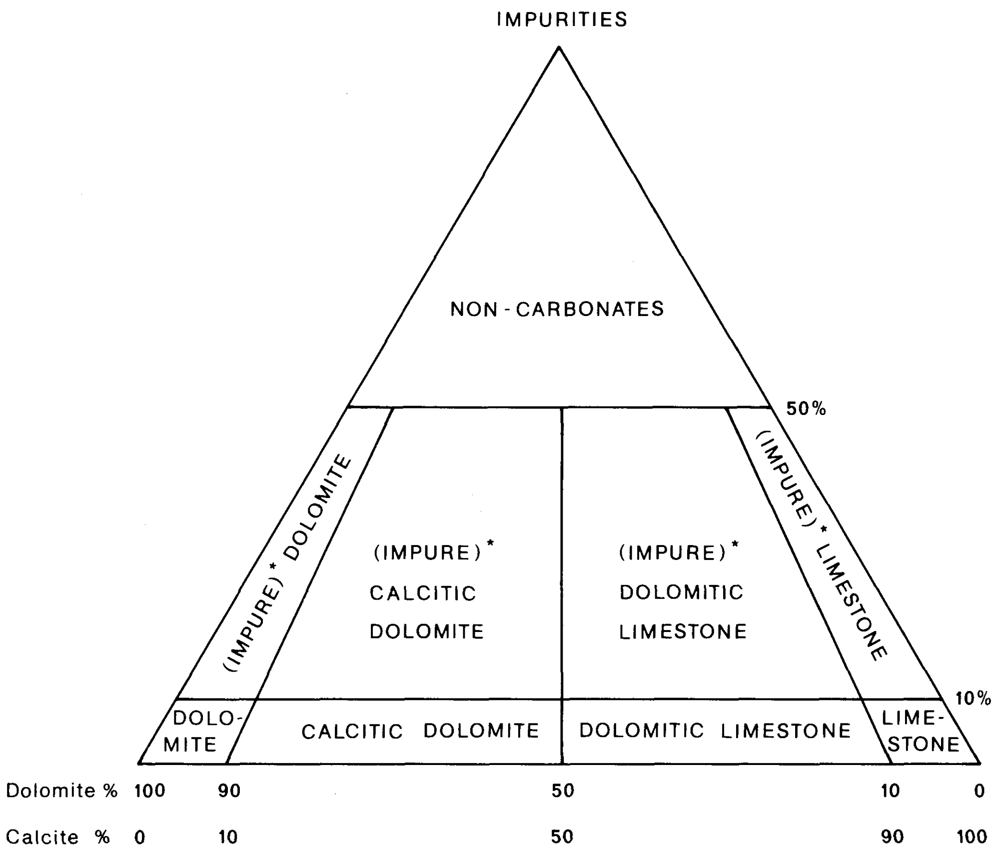
DEFINITIONS

Geological classification

Limestone is a sedimentary rock composed mainly of calcium carbonate occurring as the mineral calcite or occasionally aragonite in recent deposits. Dolomite, sometimes called dolostone, is a rock in which the carbonate is composed mainly of the mineral dolomite, Ca Mg $(CO_3)_2$. It has been estimated (Ham and Pray 1962), that approximately one fifth of all sedimentary rocks are dolomite or limestone. Rocks containing mixtures of limestone and dolomite, perhaps with other impurities, are not yet defined by a universally accepted system; however a simple chemical classification has been proposed (Leighton and Pendexter 1962), which can be expressed in the form of a triangular diagram with dolomite, calcium carbonate and impurities as the variables (Figure 1). The impurities usually take the form of argillaceous (clayey) or arenaceous (sandy) matter but may include ferruginous or other less common materials.

To define areas of high purity calcium carbonate for certain industrial purposes the Institute of Geological Sciences has introduced a chemical classification of limestone as follows:

Categories of Limestone	Composition (% $CaCO_3$)
Very high purity	>98.5
High purity	97.0–98.5
Medium purity	93.5–97.0
Low purity	85.0–93.5
Impure	<85.0



*An approximate compositional term should be substituted for the word "impure" where possible.

Figure 1 Compositional classification of limestones

	LIMESTONES			
	>10% Allochems Allochemical Rocks		<10% Allochems Microcrystalline Rocks	
	Sparry calcite cement> microcrystalline ooze	Microcrystalline ooze> sparry calcite cement	1-10% allochems	<1% allochems
Volumetric Allochem Composition: >25% Intraclasts	Intrasparite	Intramicrite (rare)	Intraclasts: Intraclastic micrite (rare)	Micrite
Volumetric Allochem Composition: <25% Intraclasts: >25% oolites	Oosparite	Oomicrite (rare)	Oolites Oolitic micrite (rare)	
Volumetric Allochem Composition: <25% Intraclasts: <25% oolites: Volume ratio of Fossils: Pellets >3:1	Biosparite	Biomicrite	Fossils: Fossiliferous Micrite	
Volumetric Allochem Composition: <25% Intraclasts: <25% oolites: Volume ratio of Fossils: Pellets 3:1 to 1:3	Biopelsparite	Biopelmicrite	Pellets: Pelletiferous Micrite	
Volumetric Allochem Composition: <25% Intraclasts: <25% oolites: Volume ratio of Fossils: Pellets <1:3	Pelsparite	Pelmicrite		

Figure 2 Textural classification of limestones (based on R.L. Folk, 1959)

In recent years several new classifications, using as criteria the texture and grain size of limestone have been evolved and one of these, based on the work of Folk (1959), is now used for mineral assessment studies in the United Kingdom. In this system the rock is described in terms of discrete particles or "allochems" which are dispersed to a greater or lesser extent in a matrix of either a microcrystalline calcite, originating as ooze and termed micrite, or a crystalline calcite cement termed "sparite". The allochems themselves may be bioclasts (fossil fragments), intraclasts (fragments of limestone), oolites (small ovoid concentrically layered calcareous grains) or pellets (small evenly sized and shaped grains). The rocks which they form are described in terms of their grain size as calcirudities (> 1 mm), calcarenites (1–0.062 mm) and calcilutites (< 0.062 mm). The matrix is also subdivided by grain size into micrite (< 4 microns), microspar (4–16 microns) and crystalline calcite cement or spar (> 16 microns). The nomenclature of the major rock types is set out in Figure 2. Another widely used classification, based on depositional texture, has been put forward by R.J. Dunham (1962).

Other terms used for the description of calcareous materials and mentioned elsewhere in this report are as follows:

Marble is a metamorphic rock which has been recrystallised by the action of heat or pressure to produce a granular limestone. The term "marble" is also used colloquially in the trade to describe a dense sedimentary limestone which is capable of being polished for ornamental purposes (eg. Purbeck Marble which is a Jurassic limestone).

Oolitic limestone or oolite is a common type of limestone characterised by the presence of abundant ooliths. It occurs extensively in the Jurassic system in England.

Chalk, is a very fine grained, white limestone or micrite occurring exclusively in the Cretaceous System. It is soft and porous in southern England but relatively hard in Yorkshire and Northern Ireland.

Marl is a general term for an intimate mixture of clay and particles of limestone or dolomite. The *Marlstone Rock Bed* is a ferruginous limestone occurring in the Middle Lias of England.

Calcspar is coarsely crystalline vein calcite used for ornamental purposes. Although not strictly a limestone it is considered in this report for convenience.

The term *lime*, as normally used, means calcium oxide and is synonymous with quicklime, burnt lime, calcined limestone or calcined chalk. However in some industries, and particularly in agriculture, "lime" may be used loosely to describe calcareous materials in general and the term "agricultural lime" is usually taken to include ground limestone, dolomite or chalk applied to the land.

The term *magnesia* is synonymous with magnesium oxide which is the essential constituent of calcined magnesite. There is no convenient term to describe the mixed oxides of calcium and magnesium which constitute "calcined dolomite" but the trade name "Doloma" is sometimes used to describe this product.

The term *magnesian limestone* is used in some classifications to describe limestones containing magnesium. The Magnesian Limestone is a Permian formation which contains a high proportion of dolomite.

Dolomitisation is the process by which limestone is converted into dolomite. In general, dolomite is not produced by the organic and sedimentation process involved in limestone formation, but by the action of magnesium-bearing fluids on existing limestone. These may be rising fluids associated with mineral veins which cause alteration of limestone adjacent to faults, fissures or bedding planes, or they may be in the form of descending solutions carrying magnesium derived from overlying formations. However most of the important dolomite deposits were formed when magnesium rich waters, concentrated by evaporation, reacted with newly formed limestones. The process begins when limestones are deposited in part of a warm, shallow sea which is subsequently subjected to evaporation to the extent that gypsum ($CaSO_4.2H_2O$) precipitates to form an evaporite deposit. If the residual waters, now relatively enriched in magnesium, gain access to the limestones, widespread dolomitisation is likely to occur. The dolomite and gypsum deposits are not necessarily in close proximity, but if they are, the dolomite may be physically affected by the subsequent conversion of gypsum to anhydrite ($CaSO_4$) which occurs in response to high temperature and pressure resulting from deeper burial under later sediments. The conversion is accompanied by a reduction in volume and the evolution of water which may disrupt adjacent formations.

Dedolomitisation is part of a process in which magnesium may be removed or partially removed from dolomite by water rich in calcium. The process begins when anhydrite adjacent to dolomite comes within the influence of surface waters. Initially the anhydrite hydrates to form gypsum and the resulting volume change disrupts the surrounding strata, allowing water to penetrate easily. Subsequently the gypsum begins to dissolve and if the resulting solution of calcium sulphate is free to circulate through the dolomite, magnesium may be preferentially taken into solution and the original dolomite may be converted into limestone. Dedolomitisation may also be affected by passage of calcium rich surface waters through or over the surfaces of a dolomite rock as part of the normal weathering cycle.

Trade classification

In BS 812: 1975, "Methods for sampling and testing of mineral aggregates, sands and fillers", rock and slag aggregates are classified on petrological grounds into the following groups:
1 Artificial, 2 Basalt, 3 Flint, 4 Gabbro, 5 Granite, 6 Gritstone, 7 Hornsfels, 8 Limestone, 9 Porphyry, 10 Quartzite and 11 Schist.
The limestone group includes all natural carbonates used for aggregate including marble and dolomite. Hence there should be no possibility of confusion in commercial descriptions at the group level, although difficulties may occur in the definitions of various types of limestone by the indiscriminate use of such terms as marble. However, the grouping is biased in that it includes seven groups for igneous and metamorphic rock and only one for limestone, although the output of limestone is more than double that of other crushed rocks and there are several varieties of limestone used for aggregate purposes between which useful distinctions can be made.

Mechanical properties

For engineering purposes, limestones, like other materials, are described according to the mechanical properties relating to their use.

An important property of rock for use as aggregate or building stone is its shear strength or resistance to crushing. Where the rock is used in block form, as in building stone, strength is determined by testing single small blocks to the point of failure, with the result expressed as a pressure. In the testing of coarse aggregates a closely-sized sample is subjected to known crushing forces in a standard container for a fixed time. The result, expressed as the percentage of material which has been reduced below a given size, is known as the Aggregate Crushing Value (ACV). Alternatively, a series of such tests can be performed under varying loads and the results extrapolated to determine the load under which 10% of the weight of the sample is reduced below a standard particle size. This quantity, known as the 10% fines value, is measured as a force (kN) and was introduced because ACV measurements tend to be unreliable in weaker rocks.

Another test, similar to that for ACV, but involving the application of a shock load, is used to determine the resistance of aggregates to impact and gives the Aggregate Impact Value (AIV).

The Polished Stone Value (PSV) is of importance in assessing the resistance of aggregates to polishing and hence their suitability for use as road surfacing material. In this test a standard surface made up of aggregate is exposed to the wear of a rubber-tyred wheel in the presence of loose abrasive. After a given time the frictional resistance of the aggregate surface is measured and the results expressed as a coefficient of friction in percentage terms.

Resistance of aggregates to surface abrasion is measured by submitting a standard sample to an abrading wheel for a fixed time. The percentage loss in weight resulting from this test is the Aggregate Abrasion Value (AAV).

Other physical properties of practical importance include water absorption and porosity, which are useful in assessing resistance to damage from frost and the effects of crystallisation of soluble salts.

Although many of the mechanical properties mentioned above and described in BS 812 are to some extent dependent on each other, their relationship cannot be expressed with great precision. The aggregate tests are essentially of a practical nature, designed to assess the suitability of a material for a particular end use. ACV and 10% fines values are a measure of the shear strength of the material by a method which would exclude many of the anisotropic effects of structural weaknesses such as bedding planes or joints. The AIV, a measure of a combination of impact resistance and shear strength, has a similar numerical value to the ACV for many materials. Resistance to abrasion depends largely on the strength of bonding between the constituent particles of a rock and is consequently related to the shear strength.

Resistance to polishing depends on mineralogical factors such as the relative hardness of constituent grains and the ease with which they are abraded to expose new rough surfaces. Grains of calcite or dolomite wear rapidly and evenly so that well-cemented limestones tend to polish easily; the more porous and softer limestones abrade too readily for polishing to occur.

USES AND SPECIFICATIONS

Limestones have been worked throughout history for such purposes as building stone, mortar, agricultural lime, metallurgical fluxes and whiting for use in whitewash. With the coming of the industrial revolution however there was a rapid increase in the demand for limestone, particularly in the expanding metallurgical and chemical industries, and for dolomite, which found a special application in furnace linings. At the same time improvements in farming practices led to a greater use of agricultural lime, to the extent that lime or limestone was the principal freight carried on some of the early canals and railways in rural areas. Expansion of population and rising living standards throughout the eighteenth and nineteenth centuries led to an increase in the use of limestone for building stone and mortar, while the Portland cement industry, initiated on a significant scale in the nineteenth century, eventually became a large consumer.

The harder limestones have been used for many years as road chippings and to a lesser extent as an aggregate in concrete. However the growth of the road building programme in the late 1950's and 1960's was such that roadstone became the largest single end use of limestone. In the same period limestone was increasingly used as concrete aggregate because of an increase in construction work generally, limitations in the supply of gravel and the substitution of concrete for brick in large structures. Exploitation of limestone and dolomite is now devoted primarily to the production of aggregate, with less than 30 per cent used for other purposes. In the aggregate field it is used mainly as roadstone or in concrete with substantial quantities going for other construction purposes such as fill or hardcore; the amount used as railway ballast is relatively small (Table 1).

Table 1 End use of limestone and dolomite aggregates in Great Britain, 1979

	Thousand tonnes	*%*
Coated roadstone	8,013	8.9
Uncoated roadstone	27,136	30.3
Railway ballast	1,006	1.1
Concrete aggregate	11,359	12.7
Other construction purposes (e.g. fill)[1]	17,134	19.1
Total for aggregate purposes	64,648	72.1
Limestone for other purposes	22,007	24.6
Dolomite for other purposes	2,937	3.3
Total for all purposes	89,592	100.0

[1] In addition 1.06 million tonnes of chalk were used in this category

Roadstone

Coarse aggregate used in highway construction is called roadstone. The structure of a typical flexible main road is shown in Figure 3. The sub-base consists of unbound or lightly bound aggregate, which distributes the load onto the subsoil (the sub-grade) so as to raise the bearing capacity above a minimum level; the road base is the main load-bearing layer of the foundation; the basecourse forms the main element in the surfacing, and is overlain by a thin wearing course which provides the texture of the road surface. Specifications for materials used in road making are given in "Specifications for Road and Bridge-Works" published by the Department of Transport and also in British Standards and some County highway authorities specifications. For most major highways, "Type 1 Granular Sub-base Material" is specified. This consists of unbound crushed rock with a size range mainly between 39 and 0.60 mm. Material finer than 0.425 mm is required to be non-plastic. Aggregate to be used within 450 mm of the road surface must be frost resistant. In addition the aggregate is expected to have a 10% fines value of 50 kN. These requirements exclude the weaker, more porous types of limestone such as chalk in England and most Jurassic limestones together with any materials which have a significant clay or shale content. The requirement is, in effect, for clean strong material with relatively low porosity.

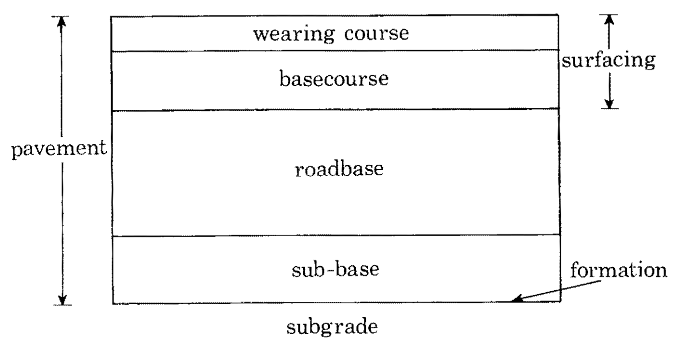


Figure 3 Cross-section of a typical highway

In Dense Bitumen Macadam, which is commonly used as roadbase material in major highways, the coarse aggregate can include rock in the Granite, Basalt, Gabbro, Porphyry, Quartzite, Hornfels, Gritstone or Limestone groups. Although the required properties are not defined rigorously by the British Standards, strength and frost resistance are important, as the specifications require the aggregate to be hard, clean and durable. "Wet Mix" and "Dry Bound" Macadams, both uncoated materials similar to, although somewhat finer than Type 1 Sub-base and which meet the specification for concrete aggregate, are also used for the roadbase.

The basecourse is usually made from Rolled Asphalt or Dense Bitumen Macadam on major roads and open textured bitumen macadam on lightly used roads. The specifications for the aggregate are similar to those used for coated roadbase materials, except that in some cases slightly less binder is required where limestone aggregates are used.

The wearing course provides a shaped riding surface which will withstand direct tractive forces and loads from traffic, protect the underlying layers from the elements and give a durable skid-resistant surface. It can be made from a variety of bituminous materials, but for major highways rolled asphalt containing a maximum of 30% coarse aggregate, with coated chippings rolled into the surface, is used most frequently.

The properties of aggregates used in the surfacing are rigorously specified to match skid resistance with various highway conditions and traffic flows. Minimum PSV and maximum AAV requirements are specified for dry or coated chippings used in the running surface and for coated materials in the basecourse and roadbase where these are used to provide temporary non-dressed running surfaces. The PSV requirements are as follows:

a. For difficult sites, which include important approaches to traffic lights, pedestrian crossings, roundabouts, major roads, sharp bends and steep hills etc., a minimum PSV of 60 is specified with higher minima in more densely trafficked situations.
b. For motorways, trunk roads and other roads carrying over 250 commercial vehicles per lane per day the minimum PSV is 55, rising to 65 where traffic is very heavy.
c. In other less demanding conditions a minimum PSV of 45 is required.
d. The PSV of coarse aggregate in rolled asphalt and dense tar surfacing to which coated chippings are applied should be not less than 45 for sites in paragraphs (a) and (b) above, while there is no limit for the sites described in paragraph (c).

Requirements for AAV are given in Table 2.

Table 2 Maximum Aggregate Abrasion Values and traffic loadings for materials used in highway running surfaces

Traffic in commercial vehicles per lane per day	*Under 250**	*Up to 1,000*	*Up to 1,750*	*Up to 2,500*	*Up to 3,250*	*Over 3,250*
Maximum AAV for chippings	14	12	12	10	10	10
Maximum AAV for aggregate in coated macadam wearing courses	16	16	14	14	12	12

*For lightly trafficked roads carrying less than 250 commercial vehicles per lane per day aggregate of higher AAV may be used where experience has shown that satisfactory performance is achieved by aggregate from a particular source.

As the softer limestones tend to have AAV's greater than 14 and the harder ones have PSV's which only exceptionally significantly exceed 45, the effect of the above requirements is largely to exclude limestone from use in road surfacing, suitable materials being provided by crushed igneous rock or sandstone. However, in the lower levels of road pavements, limestone is generally preferred to other rock types, and occasionally some impure limestones (e.g. Dalradian limestone) have PSV's high enough to be used for surfacing. Strong, angular, frost resistant aggregate with good bitumen bonding characteristics can be produced from many limestones occurring in relatively large, geographically well dispersed and cheaply worked deposits. Hence many limestones, particularly in the Carboniferous, have proved attractive as roadstone and are exploited on a large scale for this purpose. The importance of limestone as roadstone relative to other hard rock is illustrated in Table 3.

Table 3 Usage of limestone, igneous rock and sandstone for uncoated and coated roadstone in 1979

	Thousand tonnes		
	Limestone	*Igneous Rock*	*Sandstone*
Coated and uncoated roadstone	35,149	15,673	5,378

Concrete aggregate

Concrete is usually made from a mixture of cement, coarse aggregate and fine aggregate (sand) in the approximate weight ratio 1:3:2. Gravel, crushed limestone and other hard rock are used for coarse aggregate. Sand and occasionally fine crushed limestone are used as fine aggregate.

Specifications require concrete aggregates to be hard (the lower strength limit is generally specified), durable, clean and free from deleterious material which might affect the strength, durability and resistance to frost or corrosion of the concrete. In this context "deleterious material" includes clay, particularly as adherent coatings, flaky or elongated particles, mica, shale and other laminated materials, coal and other organic impurities, iron pyrites and soluble sulphates (BS 882:1973). The aggregate should not be susceptible to frost damage or subject to attack by an alkaline cement environment. This latter requirement, although not generally of importance in the United Kingdom, can affect limestones carrying amorphous silica.

Aggregates for use in particular types of concrete may be subject to additional requirements. For example, aggregate used in road pavement is expected to have a flakiness index which does not exceed 35 (that is not more than 35% by weight of the pebbles may have a least thickness less than 60% of the mean thickness). Also in structural concrete, which is expected to reach a strength of 37.5 MN/m^2 after 28 days, the 10% fines value of the coarse aggregate should be at least 100 KN. For other structural concretes the 10% fines value of the coarse aggregate should be at least 50 KN.

There are some special restrictions on the use of limestone in the top 50 mm of concrete roads. Fine aggregate containing more than 25% carbonate is prohibited altogether. Coarse aggregate made from limestone is permitted provided that it meets the requirements of an Accelerated Wear Test specified by the Department of Transport.

The relationship between the strength of concrete and the properties of its constituent aggregates is complex. Usually the strength of the aggregates is higher than that of the final concrete by a factor of about three and stronger aggregates do not necessarily produce stronger concrete.

In general, crushed rock aggregates consist of angular particles which result in a concrete of lower workability but higher ultimate strength compared with similar mixes made from gravel. Crushed rock aggregates are essential for the production of very high strength concrete.

The importance of limestone aggregates in concrete relative to other crushed rock is shown in Table 4.

Table 4 Usage of limestone, igneous rock and sandstone as aggregate in concrete in 1979 (thousand tonnes)

Limestone	*Igneous Rock*	*Sandstone*
11,359	3,278	950

It should be noted, however, that most of the gravel output (total 54 M tonnes in 1979) is used in concrete. Limestone is, therefore, second to gravel as the main source of concrete coarse aggregate.

Railway ballast

Railway ballast is specified largely on the basis of its resistance to abrasion when wet, a property in which igneous rocks generally and some quartzites have a significant advantage over limestones. Hence igneous rock (2.0 M tonnes in 1979) is usually preferred for this purpose although some limestone (0.8 M tonnes in 1979) is used. Some compact dolomites, particularly those in the Carboniferous of South Wales, have an unusually good resistance to wet abrasion and it is mainly material of this type which accounts for the limestone recorded in railway ballast statistics.

Other construction purposes

Substantial quantities of crushed limestone are used for such purposes as rock fill in embankments, backfilling of trenches or French drains and for the bedding of underground pipes. Specifications consist mainly of a size requirement and a restriction on the soluble sulphate content, although material for French drains is expected to have an ACV under 30. In addition some limestone is used as hardcore in minor building works. Because of the undemanding nature of the specifications many of the softer and more porous limestones, unsuitable for other purposes are used.

Some relatively strong limestone is used as large blocks to act as protection against wave action in reservoirs and on the faces of dams, harbours and other coastal works.

Finely ground limestone is used as a filler in asphalt. The specification requires only a certain particle size distribution, essentially that 75% of the filler is finer than 75 microns. Other specialised applications of limestone include the use of chippings, either dry or with bitumen, in drives, pathways and sports facilities.

Table 5 End uses[1] of limestone, chalk and dolomite for non-aggregate purposes in Great Britain in 1979.

	Thousand tonnes
Limestone	
Building stone	164
Cement	10,450
Agriculture	1,979
Ferrous metallurgy flux	3,757
Chemicals	2,662
Building materials	1,368
Others	1,627
Total for non aggregate purposes	22,007
Dolomite	
Agriculture Ferrous metallurgy flux, glassmaking, refractories and chemicals Others	2,937
Chalk	
Cement	13,338
Agriculture	606
Industrial and other uses	937

[1] Including material for calcination

Building stone

Limestone has long been popular as a building stone and most formations have been used for this purpose at some time, although now the use of natural stone is largely restricted to a relatively small specialist market.

The main requirement, other than aesthetic appeal, is that the rock should have good resistance to damage by the action of frost and the crystallisation of soluble salts. Stone with low porosity, or with large pores from which absorbed water can easily drain, is usually suitable as building stone, whereas stone with a large number of small pores tends to hold water and is susceptible to damage.

Building stone is worked mainly in Jurassic formations. Upper Jurassic stone from Portland and the Isle of Purbeck has for many years been the most intensely worked of the domestic building stones, its popularity being due, in part, to the coastal location of the quarries and consequent easy transport to such centres as London. Some stone is also produced from the Upper Jurassic in the Vale of Wardour.

In the Middle Jurassic, the Great Oolite has been widely worked and some "Bath Stone" is still produced in Wiltshire, together with "Taynton Stone" in Oxfordshire. The Inferior Oolite is probably more popular at present; there are several producing quarries in the Lincolnshire Limestone which market material under local names such as "Ancaster Freestone". "Guiting Stone" is a similar material produced in the Cotswolds.

The Lias is worked, notably at Edge Hill, near Banbury, where the Marlstone Rock Bed provides a brown ferruginous building stone.

Permian dolomitic limestones are still popular, particularly from the area around Tadcaster.

Polished Carboniferous Limestone, sometimes called "marble", is produced in Anglesey and Cumbria, but all true marble for this purpose is imported, mainly from Carrara, Italy. Several of the larger aggregate quarries, particularly in the Carboniferous, produce blocks which may be sold either for armouring of embankments or for walling and building stone.

Although the use of building stone has declined, there has been an increase in the use of reconstituted stone building blocks designed to resemble the natural product. The blocks often consist of limestone aggregate bound by cement which has been cast into the desired shape.

Cement

British Standard Specifications for cement are expressed in terms of the finished product and it is difficult to relate these precisely to the raw material, particularly when this is made by mixing separate lime-rich and alumino-silicate (clay or shale)- rich constituents. The specifications for ordinary and rapid-hardening Portland cement (BS 12:1978) require that the product has a certain maximum particle size, that test cubes reach a certain minimum strength after standard time intervals and that the cement does not have excessive expansion characteristics when setting (soundness). In addition to these measurements of mechanical properties, the chemical composition of the cement is specified as follows:

a. The lime saturation factor (LSF) should be greater than 0.66 and less than 1.02. Where:

$$LSF = \frac{(CaO) - 0.7(SO_3)}{2.8(SiO_2) + 1.2(Al_2O_3) + 0.65(Fe_2O_3)}$$

NB The symbols in brackets refer to the percentage by weight of each oxide in the cement.

b. The weight of acid insoluble residue should be less than 1.5%, when determined by a standard method.

c. The weight of magnesia (MgO) should be less than 4.0%.

d. The percentage of SO_3 in ordinary Portland cement should be less than 2.5 or 3.0, depending on whether the tri-calcium aluminate content is less than or greater than 5%. (This refers mainly to sulphate added in the form of gypsum but is also related to sulphur in the raw materials and fuel, depending on the nature of the process.)

e. The loss on ignition should be less than 3.0% in temperate climates or 4.0% in tropical climates.

Of the above factors only (c) is directly related to the raw material. It implies that a relatively pure limestone mixed in the ratio 4:1 with clay or shale, should not contain more than approximately 3.0% MgO.

Alone, the formula for lime saturation factor has limited relevance to specifications for raw materials, as the range of mixtures which it theoretically admits is very wide and includes materials which would probably not be used for cement making. Hence the main criterion for raw materials remains the practical one of whether they produce acceptable cement. However the cement industry applies its own specifications to raw materials which effectively complement those given in BS 12:1978. For example, most cement works in the UK require their product to have an LSF over 0.9 and many operate at about 0.98. Other controls on the raw materials include the ratio of silica to alumina and iron, $SiO_2 : Al_2O_3 + Fe_2O_3$, which is usually between 1.5 and 3, and the ratio $Al_2O_3 : Fe_2O_3$ which is usually between 1.5 and 3.5.

The main impurities in raw materials which can affect the properties of the finished cement are magnesia, fluorine, phosphates, lead, zinc, alkalis and sulphides.

Magnesia is harmful because it forms periclase (MgO) in the cement, in which form it can survive until long after concrete has hardened, after which it can hydrate causing expansion and disruption. Fluorine, usually present in raw materials as fluorite, can reduce the strength of cement if present in excess of 0.1%. P_2O_5 in excess of 0.5% and small amounts of lead and zinc oxides are also deleterious. Alkalis can affect the cement making process in that they may volatilise and condense in inconvenient parts of the plant as alkali sulphates. There may also be undesirable reactions when cements with high alkali contents are used with aggregates containing amorphous silica. Sulphides, which form calcium sulphate in the kiln, can be advantageous in that they lessen the need for gypsum additions to the cement. However in the presence of alkalis they also contribute to the formation of volatile alkali sulphates.

In the United Kingdom the industry has traditionally used calcareous materials mainly from the Cretaceous, Carboniferous or Jurassic and the presence of suitable outcrops close to markets have largely precluded the need to experiment with doubtful raw materials.

In addition to ordinary and rapid-hardening Portland cement, there are several other cements, such as sulphate-resisting cement, oil-well cement and white cement (made from a mix containing kaolin). These are made to special formulae but as they consume relatively little limestone they are not described in detail.

The location and details of raw materials used in all domestic cement works in 1980 are given in Table 6.

Table 6 Location and capacity of UK cement works grouped by geological age of local raw materials

Name	*Company*	*Location of Works*	*Geological horizon of raw material*		*Nominal annual capacity (thousand tonnes)*
			Limestone	*Clay/shale*	
Devonian					
Plymstock	Blue Circle	Plymouth, Devon	Middle Devonian	Middle Devonian	549
Carboniferous					
Weardale	Blue Circle	Eastgate, Co. Durham	Great Limestone	Millstone Grit shale	780
Ribblesdale	Ribblesdale Cement	Clitheroe, Lancs	Chatburn Limestone	interbedded shale	1111
Hope	Blue Circle	Hope, Derbyshire	Monsal Dale Limestones	Edale Shales	1279
Tunstead	ICI	Buxton, Derbyshire	Bee Low Limestones	interbedded clays	200
Cauldon	Blue Circle	Cauldon Low, Staffs	Milldale Limestone	Churnet Shales	764
Padeswood	Tunnel Cement	Mold, Clwyd	Main Limestone (Cefn Mawr)	colliery spoil	564
Dunbar	Blue Circle	Dunbar, Lothian	Upper Long Craig, Middle Skateraw	Lower Limestone Group Shales	990
Cookstown	Blue Circle	Cookstown, Co. Tyrone	Rockdale Limestone Formation	Rossmore Mudstone	441

Table 6 Location and capacity of UK cement works grouped by geological age of local raw materials (cont'd)

Name	*Company*	*Location of Works*	*Geological horizon of raw material*		*Nominal annual capacity (thousand tonnes)*
			Limestone	*Clay/shale*	
Jurassic					
Ketton	Ketton Cement	Ketton, Lincs.	Middle Jurassic (Lincolnshire Limestone)	Middle Jurassic clays	800
Rugby[1]	RPC	Rugby, Warwickshire	Middle Chalk	Lias	678
Southam[1]	RPC	Long Itchington, Warwickshire	Middle Chalk	Lias	566
Oxford	Blue Circle	Shipton-on-Cherwell, Oxfordshire	Middle Jurassic	interbedded clays	112
Aberthaw[1] and Rhoose	Aberthaw & Bristol Channel Cement	Barry, S. Glam	Carboniferous	Lias	1053
Cretaceous					
Humber[2]	Blue Circle	Melton, N. Ferriby, Humberside	Chalk	Upper Jurassic clay	294
South Ferriby	RPC	Barton-on-Humber, Humberside	Chalk	Upper Jurassic clay	664
Norman	Blue Circle	Cambridge	Middle and Lower Chalk	Lower Chalk	118
Barrington	RPC	Barrington, Cambs	Lower Chalk	Gault	499
Mason's	Blue Circle	Claydon, Ipswich, Suffolk	Upper Chalk	Boulder Clay	364
Pitstone	Tunnel Cement	Pitstone, Bucks.	Lower Chalk	Lower Chalk	924
Chinnor	RPC	Chinnor, Oxon	Lower Chalk	Lower Chalk	264
Northfleet[3]	Blue Circle	Dartford, Kent	Upper Chalk	London Clay	4018
Swanscombe[2]	Blue Circle	Dartford, Kent	Upper Chalk	London Clay	426
Rochester	RPC	Halling-on-Medway, Rochester, Kent	Lower Chalk	Lower Chalk	389
Holborough	Blue Circle	Snodland, Rochester, Kent	Lower/ Middle Chalk	Gault	371
Westbury	Blue Circle	Westbury, Wilts	Lower/Middle/ Upper Chalk	Kimmeridge Clay	713
Shoreham	Blue Circle	Steyning, W. Sussex	Upper/ Middle Chalk	Gault	375
Lewes	RPC	Lewes, E. Sussex	Lower Chalk	Lower Chalk	82
Magheramorne[4]	Blue Circle	Larne, Co. Antrim	Chalk	Recent alluvium	123

[1] Works originally based entirely on Lias which now use some imported Carboniferous limestone or chalk.
[2] Works closed in 1981.
[3] Works expected to reduce capacity during 1981.
[4] Works closed 1980.

Agriculture

In agriculture, the term lime is used for materials containing calcium or calcium and magnesium which are commonly applied to the land. Limestone and dolomite, together with their calcined products, are included in the definition, as are calcareous sands and certain calcareous industrial wastes from sugar beet refining and water softening.

The main function of lime is to reduce soil acidity. It may also be used to supply calcium or magnesium to the soil, both being essential plant nutrients, although the level of calcium is normally sufficient in most soils.

Under Ministry of Agriculture, Fisheries and Food regulations, agricultural lime offered for sale should be specified in terms of its 'neutralizing value' or ability to neutralize weak acid under standard laboratory conditions. The value is expressed as the percentage of calcium oxide in the material or its equivalent if both calcium and magnesium are present. Thus a ground dolomite with a neutralizing value of 55 would neutralize the same amount of soil acidity as material containing 55 per cent calcium oxide. The same regulation also requires the material to fall within a standard product description, as follows:

1. Burnt magnesian lime (ground or otherwise): commercial calcium or magnesium oxides containing more than 5.5 per cent of magnesium.
2. Burnt lime or quicklime (ground or otherwise): commercial calcium oxide containing not more than 5.5 per cent of magnesium.
3. Calcium hydroxide, hydrated lime or slaked lime: the product obtained by slaking burnt lime.
4. Chalk: Cretaceous limestone.
5. Chalk, ground: Cretaceous limestone reduced in size to pass a ¼-inch (6.35 mm) sieve.
6. Chalk, screened: Cretaceous limestone reduced in size to pass a sieve not exceeding 3 inches (76.2 mm), the amount passing a standard finer sieve size to be specified by the producer.
7. Limestone, ground: a sedimentary rock consisting largely of calcium carbonate containing not more than 3 per cent magnesium which has been reduced in size so that 100 per cent passes a $^3/_{16}$-inch (4.76 mm) sieve, at least 95 per cent passes a ⅛-inch (3.18 mm) sieve and at least 40 per cent passes a 100 mesh BS sieve. The actual amount passing 100 mesh BS is to be specified.
8. Magnesian limestone, ground: a sedimentary rock consisting largely of calcium and magnesium carbonates containing more than 3 per cent magnesium. Particle size requirements are identical to those for ground limestone.
9. Mixed lime: a mixture of any of the defined liming materials, excluding byproducts from manufacturing or other processes.
10. Slaked magnesian lime: the product obtained by slaking burnt magnesian lime.

Calcareous shell sands and chemical waste lime, although regarded as non standard, are usually sold on the same basis of neutralizing value and fineness as other liming materials.

The rate at which lime acts on soils is a function of particle size and chemical composition: limestone is ground not only to aid spreading but to increase the effective surface area as a means of facilitating dissolution. Chemical composition affects availability in that dolomite, because of its slower reaction with acids, tends to be slower to act than limestone. Burnt lime, which is normally slaked before application, has a much faster action as well as a higher neutralizing value. Burnt dolomite is more difficult to slake than quicklime and has a slow agricultural action.

Reaction rates are of only limited importance in practice. It has been shown that the use of very finely ground limestone is rarely worthwhile and that the slower availability of dolomite is not an important factor in most liming operation. Burnt or hydrated lime is seldom worth the additional expense compared with ground limestone for normal agricultural use unless the higher neutralizing value can be offset against considerable savings in transport costs. However the more rapidly acting forms of lime are of value where growing crops are failing due to soil acidity and immediate action is required. Similarly, drastic cases of magnesium deficiency affecting crops or cattle may require the application of imported calcined magnesite or soluble magnesium salts rather than slow acting dolomite.

Lime has always been used in agriculture, and although quick lime was once preferred because of its rapid action, its use declined with the increasing availability of cheap ground limestone. The widespread use of dolomite is relatively new and results mainly from changing agricultural practices which have given rise to more magnesium deficiencies. Also the material has a higher neutralizing value than ordinary limestone because magnesium has a lower atomic weight than calcium. Traditionally, magnesium was returned to the soil in the form of natural manure but specialization in farming has resulted in a decrease in animal population and hence manure availability in some areas.

Output of agricultural lime was strongly influenced by a government subsidy which at one time amounted to 70 per cent of the delivered and spread cost, resulting in demand reaching a maximum of 7.7 M tonnes in 1959. More recently the subsidy was at lower levels until it was finally withdrawn in 1976.

Ferrous metallurgical flux

In conventional ironmaking using a blast-furnace, hot metal is produced by the reduction of iron oxides with carbon monoxide derived from coke combustion, which also provides the essential heat for the process. During the reaction, basic oxides such as lime and magnesia combine with silica and alumina to form a slag. Slag volume and composition is now largely controlled by the need to absorb sulphur, introduced in the coke, rather than by the gangue content of the iron ore. Slag conditions are optimised to remove sulphur while maintaining fluidity and other properties in a melt which, on cooling, can be used for other purposes such as roadstone or cement substitute.

In the past, the blast-furnace burden consisted mainly of locally available raw materials such as sedimentary iron ore, coke and limestone, together with greater or lesser amounts of imported iron ore. Materials were charged directly to the blast-furnace in the required proportion although this resulted in long standing problems with fine solids which tended to impede the flow of gases through the furnace.

Large scale agglomeration of burden components prior to charging began to be developed in 1950, initially as iron ore sinter and more recently as iron ore pellets. Both methods have proved to be very successful and in most modern ironmaking less than 10% of the total burden is in the form of direct charged material. Present practice is to change the bulk of the slag forming materials as sinter, after which very small amounts of limestone, dolomite, bauxite, silica, olivine and ilmenite may be added as a final "trimming".

In current sinter preparation the mix may contain ground limestone or lime and a blend of high grade iron ores together with coke breeze, mill scale, basic oxygen slag and other steel works waste. Limestone for sintering is subject to a size specification which varies to some extent with each sinter plant, but is usually approximately 95% finer than 3 mm and 90% coarser than 0.15 mm. There are no precise chemical specifications, each plant tending to have its own quarry or external source of supply which can produce acceptable material over long periods. In general, consistency and price are the main criteria and such specifications as exist are usually related to individual contracts or sources of supply rather than to the absolute requirements of the process. Clearly high calcium carbonate with a low sulphur and phosphorous content is required, but the presence of other impurities is of less importance providing they are at a predictable level. A typical specification for limestone from Redmire Quarry, N. Yorkshire, used for sinter at Teesside is:

	Wt %
CaO	48–52
MgO	4
SiO_2	3.0 maximum
Fe_2O_3	1.5 maximum

Appropriate amounts of magnesia are beneficial in a blast-furnace and contribute towards a lowering of the slag viscosity. Until twenty years ago the magnesia content of slags, which varied from 4% to 14% approximately, was derived essentially from impurities in the iron ore. However in recent years the range of slag compositions has been standardised to approximately 8–10% MgO and with higher grade iron ores it has become normal practice to add dolomite to the sinter, although olivine or serpentine may sometimes be used.

Size requirements for dolomite are similar to those for limestone, as are the principles which control chemical specifications. A specification for dolomite used in sinter at Teesside is as follows:

	Wt %
CaO	31–35
MgO	16–20
SiO_2	3 maximum
Fe	1.5 maximum
S	0.1 maximum
Moisture	4–7

There has recently been a tendency to replace some limestone by quicklime which results in a drier, better textured sinter feed and a quicker reaction. In practice there is some increase in output, but the effect is limited and there is little prospect of replacing all the limestone by quicklime. As yet there has been no use of calcined dolomite in place of dolomite in blast-furnaces. Size specifications for quicklime used for sintering at Teesside require that the material should be 97.5% finer than 3.2 mm. Chemical requirements are broadly similar to those for limestone; for example a specification for quicklime used in sinter is as follows:

	Wt %
CaO	90 minimum
SiO_2	2 maximum
MgO	1 maximum
$Fe_2O_3 + Al_2O_3$	1.5 maximum
S	0.1 maximum

Typical mix requirements per tonne for lime, limestone and dolomite at Teesside, in a sinter containing 56% Fe are 14 kg quicklime, 31 kg limestone and 27 kg dolomite.

In 1979 1,089,600 tonnes of limestone and 858,700 tonnes of dolomite were consumed in blast-furnaces and sinter plants. Consumption of quicklime is not recorded separately. It should be noted that the proportion of dolomite in blast-furnace flux has risen steadily over the past decade.

Low grade Jurassic iron ores, now worked principally at Scunthorpe, may contain a high proportion of calcium carbonate but their importance has declined with the increased use of imported high grade iron ores. They are now used in place of limestone in the smelting of high grade ores to provide the necessary fluxing constituent and additional iron.

The use of limestone and dolomite in steelmaking has been greatly affected by the introduction of basic oxygen furnaces (BOF), which have now entirely replaced the older open hearth furnaces. Open hearths, being externally heated and relatively slow in action, could accommodate the heat requirements of the highly endothermic carbonate dissociation. However the heat input in BOF steelmaking is limited to that contained in the charge and developed in the reaction. Hence to avoid the chilling effect of carbonate dissociation, materials are pre-calcined and charged as oxides. In addition, with the shorter time available in BOF steelmaking, it is essential to have the lime present in a highly reactive form so that slag formation is rapid. The use of limestone would also give rise to slag foaming as carbon dioxide is evolved, which would be a serious hazard.

In steelmaking, the role of the flux is to remove the acidic oxides produced by the oxidation of silicon, sulphur and phosphorus in the hot metal, and hence the slag must be highly basic. The chief component is lime, but the presence of magnesia improves fluidity and reduces fluorite consumption and refractory wear. Specifications for fluxes vary locally but always demand a high quality of material in which consistency and chemical composition are of prime importance. As one unit of silica neutralises three units of lime, the presence of silica in the flux will clearly have a disproportionate effect on its activity, similarly a high sulphur content reduces the ability of the slag to absorb sulphur from the metal. The hydroxide or carbon dioxide content, resulting from incomplete calcination or subsequent atmospheric exposure of the lime, is also important as an excess of these constituents not only causes a loss of heat but can result in uncontrolled foaming.

Physical properties of importance include particle size and density. Since the rate of reaction is a function of surface area it is desirable to have small lime particles. However, as very small particles would be carried away with the exit gases, there is an optimum size requirement. When calcium carbonate is calcined, the apparent volume change is minimal although there is a 40 per cent weight loss which results in a great increase in porosity and effective surface area, but if lime is overburned, sintering occurs and the porosity is reduced resulting in a less reactive flux. Similar considerations apply to dolomite. Hence the calcination process is optimised to achieve maximum conversion with minimum sintering.

A typical specification for BOF lime is as follows:

			Wt %
CaO			95.0 minimum average
	must be	>	93.0 in 95% of samples tested
Sulphur			0.05 maximum average
		<	0.06 in all samples tested
SiO_2			1.0 maximum average
	must be	<	1.5 in all samples
Loss on ignition			2.5 maximum average
	must be	<	3.0 in 95% of samples tested
	must be	<	4.0 in 99% of samples tested

75% of the material should fall in the range of 38–13 mm
At least 95% should be coarser than 5 mm.

Similar requirements apply to calcined dolomite used in steelmaking, a typical specification being:

	Wt %
MgO	39.0%
CaO	57.0%
SiO	0.75%
Fe_2O_3	1.35%
Al_2O_3	0.4%
S	0.05% max
Mn_2O_3	0.22%
CO_2	0.5%

Bulk density 1.5 to 1.7 tonnes/m^3, size grading 5–44 mm, specific surface area 2.1 m^2/gram.

Consumption of fluxes at Teesside in basic oxygen furnaces involves additions of 57 kg of lime (CaO) and 23 kg of calcined dolomite (CaOMgO) per tonne of steel. Electric arc furnaces used primarily for melting scrap require approximately 32 kg of lime and 12 kg of calcined dolomite per tonne of steel.

The increased use of lime and calcined dolomite resulting from the introduction of BOF steelmaking in the 1960's stimulated considerable increase in demand for lime and led to the installation of several new calcining plants. In recent years lime consumption in steel furnaces has remained fairly constant despite a significant drop in crude steel production. This is due largely to the change from open hearth to BOF steelmaking and has been almost entirely at the expense of ground limestone consumption.

The Iron and Steel Industry Statistics show that consumption of lime in steelmaking in 1979 was 1,322,600 tonnes, raw and burnt dolomite was 323,200 tonnes and limestone was 116,200 tonnes. The limestone together with some dolomite, was mainly consumed in the few remaining open hearth furnaces then in operation. In steelmaking as in blast-furnaces there has been a steady increase in the proportion of calcined dolomite to lime used in recent years.

Iron foundaries may also use some lump limestone for flux in cupola furnaces to absorb some of the impurities from the charge, although the total amount used for this purpose is relatively small and there are no published specifications.

Refractories

Calcium oxide, melting point 2600°C, magnesium oxide, melting point 2800°C and mixtures of the two oxides occurring in calcined dolomite, melting point 2300°C, all have good resistance to basic steelmaking slags and when correctly fired can be used as refractories. However, lime alone is very easily hydrated and the resulting practical difficulties have so far prevented it being used on other than an experimental scale. In contrast, magnesia is relatively free from hydration problems and its presence in calcined dolomite inhibits hydration of the lime constituent sufficiently for the material to be a practical refractory.

Calcined dolomite or "Doloma" refractories were used mainly for the maintenance or fettling of basic open hearth furnaces which normally demanded 14–60 kg of doloma per tonne of steel, compared with an initial installation requirement of only 1 kg/tonne in a new hearth. Consumption has declined with the obsolescence of open hearth furnaces, although electric arc furnaces have similar but slightly lower requirements.

Basic Oxygen Furnaces use tar-bonded doloma blocks in which the doloma has been crushed, mixed with tar and pressed into a block prior to heating at 250–350°C. This treatment is necessary to prevent hydration and improve retention of carbon during use.

Magnesia refractories are significantly more expensive than those based on doloma. They are employed extensively for specialist purposes where a high performance refractory is required in steelmaking, non-ferrous metallurgy, glassmaking furnaces, cement kilns and calcium carbide furnaces.

Over the last five years there has been an increasing trend towards the use of magnesia enriched doloma and tar-bonded magnesia in BOF linings at the expense of normal doloma. In 1972 average BOF linings in the United Kingdom were composed of 80% doloma, but by 1977 this proportion has fallen to approximately 45% doloma, the balance consisting of 42% enriched doloma and 13% magnesia.

Magnesia is also added to chromium oxide (chrome) to make chrome-magnesite (more than 50% chrome) and magnesite-chrome (less than 50% chrome) refractories. Like magnesia these materials have a widespread use as high performance refractories. They have considerable strength at high temperature and are of particular value in the roofs of metallurgical furnaces.

Glass manufacture

Most commercial glass consists essentially of silica together with soda and lime; the lime being partly replaced by magnesia for some purposes. Lime is introduced into the glass melt in the form of pure limestone and magnesia is obtained by adding dolomite.

Magnesia is used specifically because it inhibits the devitrification process, the effects of which would otherwise be particularly detrimental to the properties of glass used in windows. In most glass containers and for other uses devitrification effects are unimportant and the presence of an inhibitor is not usually necessary. Hence the composition of flat glass typically includes 4% MgO together with 8% CaO while in container glasses the magnesia is insignificant except for some green glass which contain 1.5–2.0% MgO. The lime content of containers varies slightly with the type of glass but on average colourless flint glass, which accounts for 70% of all glass containers, contains 10.5% CaO while amber and green glass contain 9.7%.

In 1979 a total of 3.07 million tonnes of glass were produced of which 2.08 million tonnes were used for containers, 0.52 million tonnes for flat glass and the balance in miscellaneous categories. Assuming an ideal composition for dolomite and the average glass compositions given above it can be estimated that approximately 96000 tonnes of dolomite and 22000 tonnes of limestone were consumed in the manufacture of flat glass. Similarly by assuming an average CaO content of 10.3% and a consumption of 14000 tonnes of dolomite in green container glass it is estimated that 375000 tonnes of limestone were used in the manufacture of container glass. The miscellaneous categories include special glasses used for oven ware, scientific equipment, electric lamps, drinking glasses and glass fibres, of which approximately 200000 tonnes is lime-soda glass containing approximately 10% CaO derived from 36000 tonnes of limestone. The remainder consists mainly of lime-free glass. Hence for 1979 it can be inferred that a total of 433000 tonnes of limestone and 110000 tonnes of dolomite were consumed by the glass industry.

Flat glass manufacture in the United Kingdom is carried out entirely by Pilkington Brothers Ltd., who operate their own dolomite quarry in the Permian near Doncaster. Hence there is relatively little domestic trade in dolomite for flat glass making and no published specifications are available. However, the iron content is important and as British dolomites seldom contain less than approximately 0.2% Fe_2O_3, it is necessary to import dolomite when high purity material is required. In recent years dolomite has been imported, mainly from Spain, most of which was high purity material for use in flat glass manufacture (Table 22).

Limestone used for glassmaking is produced from several quarries, mainly in Derbyshire, and although there is some tendency for consumers to take supplies from particular sources over long periods, internal trade is significant as the quarries are not owned by glass manufacturers. Specifications used in the trade are based on BS 3108:1958—Limestones for making colourless glasses, which lays down the following chemical requirements:

1. The CaO content should not be less than 55.2% (98.5% $CaCO_3$)
2. The total iron content expressed as Fe_2O_3 should not exceed 0.035%
3. The total non-volatile matter, including silica, insoluble in hydrochloric acid should not exceed 1.0%
4. The organic matter should not exceed 0.1%
5. Colouring elements, other than iron, should not be present to an extent sufficient to produce a detectable colour in the glass.
6. If impurities such as manganese, lead, sulphur and phosphorus are present to the extent of 0.1% individually, when expressed as oxides, their presence and amount should be declared by the vendor.
7. Any limiting value for alumina and magnesia should be the subject of agreement between the buyer and vendor.
8. The maximum moisture content should be agreed between the buyer and vendor and should not normally be greater than 2%.

In addition limestone for use in tank furnaces is required to be finer than 4.76 mm and 75% coarser than 0.124 mm; for use in pot furnaces it is required to be finer than 3.175 mm and 95% coarser than 1.20 mm.

Although these requirements appear to be stringent they have been drawn up in the knowledge of the types of limestone available and such is the quality of many domestic deposits that no difficulty is encountered in supplying the industry, nor has there been any need to import material from abroad. However, within limits, consistency is probably of more practical value to the industry than precise chemical specifications.

Chemical and related industries

Solvay process

The most important application of limestone in the chemical industry is in the ammonia-soda, or Solvay, process for the production of sodium carbonate operated by Imperial Chemical Industries at Winnington, Cheshire.

The process involves the reaction of carbon dioxide with a solution of brine and ammonia to produce ammonium chloride and a sodium bicarbonate precipitate. The precipitate is recovered and heated to produce sodium carbonate together with some carbon dioxide which is recycled. The ammonium chloride solution is reacted with calcium hydroxide, as milk of lime, to produce ammonia for recycling together with a calcium chloride byproduct which largely goes to waste as production is well in excess of the demand. The reactions can be represented as follows:

recycled ammonia

$$2NaCl + 2H_2O + 2NH_3 + 2CO_2 \rightarrow \begin{cases} 2NH_4Cl + Ca(OH_2) \rightarrow 2NH_3 + 2H_2O + CaCl_2 \\ + \quad 2NaHCO_3 \rightarrow CO_2 + H_2O + Na_2CO_3 \end{cases}$$

recycled carbon dioxide

The calcium hydroxide and carbon dioxide consumed in the process are obtained in the required proportion by calcining limestone and slaking the lime product. The necessary kilns are an integral part of the Winnington plant and all the limestone is obtained from Tunstead Quarry, Buxton, owned by Imperial Chemical Industries. Approximately 1.5 million tonnes of high purity limestone (nominally containing at least 98.5% $CaCO_3$) are consumed annually in the process. However, as there are no external purchases, precise specifications are not required.

Sugar refining

Both lime and limestone are used in the sugar industry as part of the purification process.

In the processing of sugar beet, the vegetable is cut into thin slivers from which the soluble constituents are extracted by leaching with water. The resulting solution is then treated with milk of lime which raises the pH causing colloidal impurities to flocculate and certain inorganic impurities to precipitate. Carbon dioxide is then blown into the sugar juice to reprecipitate the original lime as calcium carbonate and subsequent filtration gives a clear solution from which the sugar can be crystallised after evaporation. The settled material, which contains significant amounts of nitrogen, phosphorus and magnesium, is eventually sold for agricultural purposes.

The treatment of sugar cane is similar, except that a crude crystalline extract is imported and a solution of this material forms the feed to the liming process carried out in the United Kingdom.

The British Sugar Corporation, the main user of the beet process, consumes approximately 400,000 tonnes of limestone per year, all of which is derived from quarries in the Buxton area. This is burnt in kilns at the refineries and both the carbon dioxide and lime products are used in the process, the lime being slaked in the process water. High grade limestone containing at least 98% calcium carbonate with a low silica content is normally required although there are no formal specifications.

About 10,000 tonnes of lime annually are purchased externally by the British Sugar Corporation to augment supplies from their kilns, and similar quantities are probably used in cane sugar refining by Tate and Lyle Ltd., in a process based on purchased lime together with carbon dioxide derived from furnace gases. In addition the British Sugar Corporation consumes 5,000 tonnes of lime annually for effluent water treatment.

The Solvay Process and sugar beet refining account for almost all of the consumption of limestone in the chemical and related industries. All other chemical processes consume calcined material, purchased as quicklime or hydrated lime. In these cases specifications laid down by the consumers are not of great importance since lime is generally produced only from high quality materials.

Magnesia production

United Kingdom production of magnesia comes entirely from the sea-water-magnesia plant at Hartlepool, operated by Steetley Minerals Ltd., which has a nominal annual capacity of 0.25 million tonnes of magnesia and is based on the use of dolomite from a nearby Permian limestone quarry at Thrislington, Co. Durham.

Magnesium is present in sea-water to the extent of approximately 0.2% by weight MgO. The extraction process is based on the low solubility of magnesium hydroxide, compared with calcium hydroxide, which allows for preferential precipitation under alkaline conditions.

In the production process, sea-water is initially treated with a small quantity of acid which, by decomposing calcium bicarbonate, removes carbon dioxide and prevents subsequent precipitation of calcium carbonate. After filtration the sea-water is then treated with "dolime" slurry (slaked calcined dolomite) which raises the pH and precipitates magnesium hydroxide. Prior to precipitation, large amounts of magnesium hydroxide seed crystals are added to improve the settling characteristics of the solid product which would otherwise be finely divided and difficult to handle.

Although hydrated lime is sometimes used abroad to produce the necessary alkaline conditions, United Kingdom practice has usually involved the use of "dolime", one advantage being that additional magnesia derived from this source is recovered in the precipitate, which effectively doubles the yield per unit of sea-water. However, limestone may be used occasionally when a particularly pure product is required.

Following precipitation and thickening, most of the magnesium hydroxide is recycled for use in the seeding process; the remainder is filtered and subsequently most of it is calcined under varying temperature conditions to produce dead-burned magnesia or caustic-calcined magnesia.

The most important use of magnesia is as a refractory. Dead-burned magnesia is used extensively in metallurgical, cement and glass making refractories but its main outlet is in the linings of oxygen steelmaking vessels. Caustic-calcined magnesia is used in a wide variety of industries including agriculture, animal feed stuffs, chemicals, paper making, uranium processing etc.; some magnesium hydroxide is also consumed in the chemical industry. However, an extensive description of the uses of magnesia and its derivatives is beyond the scope of this publication.

Magnesium chemicals

Magnesium chemicals are mainly derived either from natural magnesite or from the product of the sea-water process. However calcined dolomite is the starting point for some chemicals and particularly for magnesium carbonate produced by the Pattinson process, in which dolomitic lime is reacted with carbon dioxide and water to give soluble magnesium bicarbonate together with a calcium carbonate precipitate. After filtration the liquid is boiled to recover the final product which is used with asbestos for thermal insulation and in the glass and ceramic industries.

Lubricant additives

Lime is used in the oil industry in the manufacture of certain additives for engine lubricants. These consist of the calcium derivatives of organic acids which neutralize acidic vapours produced during combustion and prevent excessive corrosion.

The compounds are specific to the oil company concerned and in the United Kingdom, calcium alkyl-salicylate, calcium naphthenate, calcium phenate and calcium sulphonate are those commonly used. The manufacturing processes involve reacting lime with the appropriate organic acid to produce an organic salt. Further treatment with lime and carbon dioxide is then carried out to produce a modified salt which is capable of neutralizing more acidic vapour than would be theoretically expected. This phenomenon, known as overbasing, involves the adsorption of molecules of calcium carbonate onto the surface of the calcium salt to a varying degree, depending on the application and most lubricating oils contain these additives. Motor oil is probably the most important single use on account of the large quantities involved, although the proportion of additive is relatively small. Overbased additives are used most intensively in the marine field where cheap diesel oil containing a high proportion of sulphur is used. No statistics are available for the quantity of lime consumed in oil additives, but it probably involves some 10,000 tonnes annually.

Coal byproducts

Lime is used in the recovery of ammonia from coal distillation. In coke ovens at steelworks and at smokeless fuel plants, a distillate of gas, ammonia and tar is produced from which the ammonia is extracted by solution in water. The resulting ammoniacal liquor is subjected to steam distillation from which most of the ammonia is recovered as a condensate, although some remains in the liquor in the form of ammonium chloride and other relatively stable ammonium salts. This "fixed ammonia" is usually treated with a slurry of calcium hydroxide which decomposes the salts with the release of ammonia.

As a means of producing ammonia the process is economically marginal and often carried out to avoid discharging ammonia-bearing effluents. Some plants have substituted caustic soda for calcium hydroxide, largely to avoid the inconvenience of handling suspensions and in some areas the untreated fixed ammonia is still discharged along with other waste liquids. Much depends on the type of carbonisation process in use and the local situation regarding effluent discharge.

There are approximately forty plants currently in operation in the United Kingdom, the main operators being the British Steel Corporation, the National Coal Board, and Coalite and Chemical Products Ltd. There are no reliable estimates of lime consumption for this purpose although the figure is probably in excess of 10,000 tonnes annually.

Low temperature carbonisation plants, which make certain types of smokeless fuel, also produce tar from which a light crude fraction containing phenol is obtained. This is extracted with caustic soda as the soluble sodium salt, and reacted with carbon dioxide, obtained from fuel gases, to release the phenol. The residual solution containing sodium carbonate is then treated with lime to regenerate the caustic soda. Conventional coke ovens are operated at too high a temperature for the production of significant quantities of phenol, hence this process is relatively restricted in its application. United Kingdom consumption of lime for this purpose has been estimated by the British Carbonization Research Association to be approximately 6500 tonnes annually.

Alumina extraction

In the Bayer process for the extraction of alumina from bauxite using caustic soda, lime is used for recausticising sodium carbonate formed during the reaction. As only one plant now operates in the United Kingdom (British Aluminium, Burntisland), the amount of lime used for this purpose is relatively small. During the Bayer process cycle the caustic soda absorbs some carbon dioxide from the atmosphere to form sodium carbonate, which when the residual liquor is reconcentrated, is precipitated and subsequently treated with lime to produce further caustic soda for re-cycling. Further details of the Bayer Process are given in Mineral Dossier No. 20, Bauxite, Alumina and Aluminium.

Tanning

In the tanning industry both lime and dolomite have essential functions in the process and limestone or lime may be used in the treatment of effluents. Hydrated lime is used for the removal of hair or wool from hides. The skins are normally treated in a pit, rotating drum or stirred bath with a dilute solution containing hydrated lime and sodium sulphide which causes them to swell and acts as a depilatory. If the hair is of value, a concentrated mixture of hydrated lime and sodium sulphide is applied as a paint to the flesh side of the hides. The chemicals eventually penetrate to the roots causing hair release without contamination. Approximately 4000 tonnes of hydrated lime per annum are used for hair removal.

Dolomite is used extensively in one of the major tanning processes known as chrome tanning. Chromium sulphate ($Cr_2(SO_4)_3$) is absorbed by leather only when natural acidity has been reduced by conversion to a solution of the basic salt, $Cr(OH)SO_4$. A subsequent increase in basicity, to $Cr_2(OH)_3SO_4$, causes the salt to precipitate within the leather. Dolomite in contact with the chromium solution is used to change the basicity of the chromium solution during the process. Attempts to use calcium carbonate or lime have proved unsuccessful because an impervious layer of calcium sulphate builds up on the particles and stops the reaction. When dolomite is used the magnesium sulphate product goes into solution rapidly, leaving a porous layer of calcium sulphate which allows for further reaction. No statistics of dolomite consumption in the leather industry are available.

Effluents from tanneries are acidic and are normally treated with lime to neutralise the liquids to an acceptable level before discharge, but there is no information available on the quantities of lime used for this purpose.

Wire drawing

Wire is produced by drawing rods or coils of thick-section metals through hardened steel dies until the required diameter is reached. The dies are lubricated using a soap powder and, in the case of steel, it is necessary to prevent the surface of the wire from becoming pitted by carbon derived from soap which burns in the die because of friction. This is achieved by washing the wire with milk of lime which dries as a thin coat and acts both as a lubricant and as a refractory.

Gelatin manufacture

Gelatin is obtained from animal flesh, skin and bone by processes involving the use of lime.

In the treatment of bone, the raw material is initially degreased by crushing in water then moved to an acid leaching plant where it remains in contact with hydrochloric acid for up to three days. The products of the reaction include a soluble phosphate fraction and an insoluble organic residue known as ossein. The solution of monocalcium phosphate is treated with milk of lime to obtain a precipitate of di-calcium phosphate which is marketed. The ossein is soaked in milk of lime for up to six months resulting in the conversion of the original organic material to gelatin, which is subsequently extracted with water, concentracted and allowed to gel.

The treatment of flesh and skin involves a similar process, except that the skins are initially dehaired by sulphide treatment, after which they are soaked in milk of lime in the same way as the ossein.

Statistics of lime consumption in gelatin manufacture are not collected, but it seems unlikely that more than 10,000 tonnes of lime annually is used.

Water Treatment

Potable water

Lime is used in the treatment of drinking water for pH control and for water softening.

In areas of lime deficient soils and wet peat-covered uplands, such as are frequently found in northern and western parts of the country, surface waters collecting into reservoirs are often acidic and pH values as low as 3.8 are not unusual. Such water would be corrosive to the distribution system and might accumulate lead in solution to a hazardous level. In these circumstances lime, mainly as hydrated lime, is used by water supply authorities to bring the pH to 7 before the water is distributed.

Lime based processes for the removal of non alkaline (permanent) and alkaline (temporary) hardness from water have been used for many years and are still of importance although several newer processes have been developed. Temporary hardness, conferred by the presence of soluble bicarbonates of calcium and magnesium, can be reduced by treatment with hydrated lime or milk of lime as follows:

$$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2\,CaCO_3 + 2H_2O$$
$$Mg(HCO_3)_2 + 2Ca(OH)_2 \longrightarrow Mg(OH)_2 + CaCO_3 + 2H_2O$$

The production of insoluble calcium carbonate or magnesium hydroxide facilitates the progress of the reactions but as the calcium carbonate is slightly soluble not all the hardness is removed. The relatively slow rate of reaction between lime and the bicarbonate requires the use of large reaction tanks. There is also a practical problem of using filtration or sedimentation to separate the water from the precipitate together with the disposal of large quantities of waste sludge. However the cheapness of the lime together with the fact that the presence of excess lime clarifies the water have combined to ensure the survival of this process over many years.

Permanent hardness is mainly caused by the chlorides, sulphates and nitrates of calcium and magnesium. In treatment by the lime soda process the magnesium salts are first converted by lime to insoluble magnesium hydroxide and calcium salts. The soluble calcium salts are then removed as calcium carbonate after treatment with soda ash:

$$MgCl_2 + Ca(OH)_2 \longrightarrow Mg(OH)_2 + CaCl_2$$
$$CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3 + NaCl$$

This process is only occasionally used in public water supply treatment in the United Kingdom, largely because the limited solubility of calcium carbonate leaves a residual hardness, and because of the cheapness of alternative processes based on ion exchange.

Sewage

Hydrated lime or slaked lime is used extensively in the treatment of sewage. The main effect is to raise the pH of the raw sewage to a level at which finely dispersed organic material forms flocculated particles. Material in this condition settles relatively rapidly and is easily dewatered mechanically to produce a clear effluent.

Lime may also be used to treat sewage sludge used as a fertilizer. Such treatment, known as stabilization, reduces bacterial activity, objectionable odours and the content of pathogens. It is estimated that approximately 20,000 tonnes p.a. of lime are used in sewage treatment.

Industrial effluent

Lime is used in the final stage of many industrial processes to avoid discharging undesirable material in rivers or local authority sewage systems. The processes involved are too diverse to be described in detail, but basically the lime is used to neutralize acidic waste waters, to flocculate finely divided organic matter and to precipitate soluble heavy metals such as chromium, copper, iron, nickel and zinc etc. Lime is particularly important in treating effluent from the textile, food, brewing and metal-forming industries.

Building Materials

Lime is an essential constituent of several materials used in the building industry including mortar, plaster, calcium silicate bricks, aerated insulation blocks and whitewash. Mortar, used for jointing units in brickwork, blockwork or masonry is commonly made from mixtures of cement, lime and sand. The proportions used vary according to loading of the structure and the degree of protection required from atmospheric conditions, but for normal purposes the mix used is 1 part cement to 1 part lime to 5 or 6 parts of sand by volume. Where heavy loads or severe exposure to weather are involved the proportion of cement is increased and for internal work the proportion of lime is increased. The presence of lime improves workability and retards the rate of hardening so that slight movements during drying out can be accommodated without weakening the bond and allowing moisture penetration. The lime also modifies the strength of the mortar so that it remains less than the strength of the units being bonded, allowing the release of stresses in brickwork after hardening without damage to the bricks.

For the preparation of mortars on building sites, hydrated lime delivered in paper sacks, is normally used, although in some areas a factory produced lime putty, made by slaking quicklime with excess water, may be substituted. However the on-site mixing of mortar is diminishing in favour of ready-to-use cement-lime-sand mortars or lime-sand mixes which require the adddition of cement and water. These factory made mixes use quicklime or hydrated lime as starting materials.

Specifications for limes used in mortars are given in BS 980:1972, "Specification for Building limes" and in BS 4721:1971 "Specifications for ready-mixed lime-sand for mortar".

Plaster

For internal plastering lime may be used either as an additive to gypsum plasters or in cement-lime-sand plasters. Mix designs depend on the type of surface to be covered, whether the mix is for undercoat or finishing coat and on the environment; for example cement-lime-sand plasters have a better resistance to damp conditions than material containing gypsum and are always used when the surface is in continuous contact with water. Examples of recommended mixes for use as undercoat on normal brickwork include, by volume, 1 part gypsum plaster: 3 parts lime: 9 parts sand or 1 part cement: 2 parts lime: 8 or 9 parts sand. Finishing coats on both undercoats can have 0–½ parts of gypsum plaster: 1 part lime: 0–1 parts sand. In addition the second undercoat can be finished with 1 part cement: 2 parts lime: 8–9 parts sand.

In general the effect of the lime is to improve workability and water retention of the wet plaster permitting a good alignment to be achieved with high productivity. The relative cheapness of the raw material enables thick coatings to be used which allows a better covering of poor surfaces. Lime also inhibits efflorescene, minimises shrinkage cracking, inhibits corrosion of steel and provides a high impact strength.

External rendering

Materials for the external rendering of buildings are made from mixes of lime, cement and sand to which pigments may be added and to the surface of which ornamental coarse aggregate may be applied. The proportions are generally similar to those used in mortars.

The effect of the lime is to improve workability and increase the setting time which facilitates the use of mechanical equipment and allows time for tooling or other surface finishing. Moderating the hardening rate relieves stress which might otherwise cause cracking or failure of adhesion to the underlying surface. Lime also produces a softer more porous surface which is less liable to craze than one which is dense and impervious.

Coarse ornamental material applied to external rendered surfaces is known as exposed aggregate and several aggregates of attractive appearance may be used for this purpose. Calcspar, or vein calcite, is used almost entirely as an exposed aggregate and is produced mainly in Derbyshire, often as a byproduct of fluorite and barite. The crushed calcite tends to form translucent rhomboidal cleavage fragments which provide an attractive surface on external walls.

Limewashes

Limewashes are a cheap traditional form of wall decoration, still widely used in old buildings without damp-proof courses where the walls contain varying amounts of water which must be free to evaporate through a porous covering. Because of their mild germicidal properties, cheapness and ease of application, limewashes are also used extensively in agricultural and industrial buildings.

Limewashes are usually made by adding water to quicklime or hydrated lime to produce a paste of the desired consistency; however, other constituents such as tallow, salt, alum, animal glue, trisodium phosphate, formaldehyde and pigments may also be embodied in the mix, and several formulations are commonly used.

Soil stabilisation

On wet building sites, where the presence of clay makes for difficult working conditions, lime may be used to reduce the plasticity of clay and thereby stabilise the "soil" (the term is used in an engineering sense: top soil, containing organic matter, is removed before treatment). The addition of lime flocculates the finely divided minerals into larger particles resulting in a marked change in plasticity and causing the clay to behave as if it were much drier. Over a period of weeks the material begins to harden as the lime reacts with the clay minerals to form calcium silicates and calcium aluminates, compounds normally found in setting concrete, until a hard mass is formed.

The amount of lime required is from 2–6 per cent by weight of the clay, to a depth of about 15 cm. For application the clay is usually first scarified to the required depth, hydrated lime is then spread over the surface and mixed into the clay using a rotary tiller after which the site is compacted by rolling. Otherwise, if the site will not carry machinery a significant improvement may be obtained by spreading the lime manually. It is also possible to mix the lime and excavated clay in a mixing plant before spreading the material.

Calcium silicate bricks

Calcium silicate bricks are made from a mixture of lime and sand which may contain other aggregates such as gravel or crushed rock, together with pigments. The bricks are moulded to the same size as clay bricks, in high pressure presses and hardened in autoclaves over a period of 4–15 hours depending on the steam pressure used.

In the silo or reactor process, ground quicklime and aggregate are mixed with an excess of water and allowed to hydrate in a silo for up to twenty four hours before being remixed and pressed. In the drum hydration process, ground quicklime and aggregate are mixed with a small excess of water in a drum in the presence of low-pressure steam which accelerates hydration; mixing is completed in a mill where the residual water necessary for pressing is incorporated. Occasionally dry hydrated lime is used in which case the constituents are mixed in a mill with sufficient water for pressing.

Specifications for the lime are not very rigorous, but in general a good quality commercial quicklime for this use would be expected to contain 90–95% of available calcium oxide and material containing less than 80% would be unsuitable. The presence of magnesia is detrimental as it is liable to hydrate and expand in the autoclave. Full specifications for the manufacture of calcium silicate bricks are given in BS 187 Part 2:1970 "Calcium silicate (sandlime and flintlime) bricks".

The production of calcium silicate or concrete bricks in the United Kingdom is small compared with that of clay bricks: approximately 4,890 million bricks were produced in 1979 of which 206 million were calcium silicate bricks, 383 million concrete bricks and the remainder clay bricks.

Aerated concrete

Certain precast lightweight concrete blocks are characterised by a cellular structure produced by the chemical liberation of gas within the mix. They are made by the reaction of lime and water with powdered aluminium, or occasionally powdered zinc, which results in the production of hydrogen according to the following reactions:

$$2Al + 3Ca(OH) + 6H_2O \longrightarrow 3CaO\ Al_2O_3\ 6H_2O + 3H_2$$
$$Zn + Ca(OH)_2 \longrightarrow Ca\ Zn\ O_2 + H_2$$

In the manufacturing process a slurry of lime and ground silica, which may also contain cement, is mixed with powdered metal and poured into moulds; after the expansion is completed, the concrete blocks are steam cured in an autoclave to form calcium silicate which imparts the necessary strength. If cement is present, the curing merely accelerates the normal cement hardening process.

Fillers, powders and pharmaceuticals

Calcium carbonate in finely divided form is used extensively in the loosely defined fields of powders and fillers. The raw materials include ground limestone or finely divided chalk (known as chalk whiting) and chemically precipitated calcium carbonate, produced specifically for the purpose or as a byproduct of other operations.

Large tonnages of fine limestone are produced as a byproduct of aggregate working, the material being used largely for agricultural spreading or as a filler in asphalt. However some of this material, together with limestone and chalk whiting specially produced for the purpose, finds an outlet as special powders and fillers.

Specifications vary greatly, as do prices, and it is often difficult to equate end uses unambiguously with specific grades of raw material as price is often the main factor. At one time, only chemically precipitated calcium carbonate and, to a lesser extent, chalk whiting could meet the finer particle size requirements, but with recent improvements in technology it is now possible to derive fine material from relatively tough limestones. Hence the major physical factor in determining the choice of raw material is now probably colour. Even the highest purity domestic limestones have a slightly cream colour that may prevent them being used in colour sensitive articles such as paint and paper, whereas whiting produced from chalk has much superior colour and brightness characteristics. However, for the highest brightness, limestones and marbles are imported from Italy, France, Spain and Norway, or precipitated material is used. Measurement of brightness values for purposes of comparison is not straight-forward as the values are influenced by particle size. In the field of paper coatings, where the finest material is used (approximately 80% below 2 microns), the following approximate brightness values apply:– precipitated calcium carbonate 94–95; Italian Carrara marble 93; E. Grimstead, Wilts., chalk whiting 86; Queensgate, Humberside chalk whiting 85; Quidhampton chalk whiting 83.5. Hard domestic limestones are not used in paper coatings and are not normally ground to such a fine size, but it is estimated that in general the best material from the Carboniferous would have a brightness value well below 80. Nevertheless, ground limestone, mainly from Derbyshire, is used as a filler where brightness is not critical.

Chalk whitings fall into two main types depending on their origin. Material from Humberside, being harder, has a lower oil absorption and binder requirement than whiting produced from chalk in southern England.

Precipitated calcium carbonate may be produced, either as a precipitate from milk of lime or as a byproduct of water softening, to a very high purity and in several very fine uniform size ranges.

Details of the various uses of powders are as follows:

Coal mining

Limestone dust is used to limit coal dust explosions by providing inert particles which absorb heat and prevent further ignition. Limestone is used because, being free from silica, it does not present a respiratory health hazard. Its heat absorbing properties are provided essentially by the heat capacity of the powder and as far as is known the endothermic thermal dissociation of the calcium carbonate is not a significant factor in explosion suppression. In practice limestone dust is scattered in underground roadways to increase the non-combustible content of coal dust to within the range 50–75 per cent, depending on the volatile content of the coal. It is also piled loosely on shelves, known as stone barriers, in roadways carrying conveyors and in other areas where ignition may occur.

The National Coal Board specifications for limestone dust require that the material should contain less than 3% free silica and have a size distribution in which 90% is finer than 250 microns and 50–75% is finer than 63 microns. The dust should be easily dispersed in air and free from any tendency towards caking. It should also be of a uniformly consistent colour when supplied to a colliery or group of collieries. There are additional specifications for dust which has been specially treated with water repellant to avoid caking.

As the specifications are not very demanding chemically, a wide range of limestones or dolomites can be used. However, in practice most material used for this purpose is obtained from Carboniferous or Permian limestone outcrops adjacent to coalfields. Recent National Coal Board estimates suggest that approximately 130,000 tonnes of limestone dust are used annually in coal mining in the UK.

Animal feedstuffs

Finely divided calcium carbonate is used extensively in animal feedstuffs, particularly in poultry feed (5 per cent calcium carbonate), and cattle or pig feed (1 per cent calcium carbonate) to provide essential calcium. Total quantities used for these purposes are believed to be about 0.25 million tonnes annually. There are no published specifications, both limestone and chalk are used for this purpose and a fairly pure material with low magnesia content is usually required.

Paint

Whitings with good colour and fine particle size are used as low cost extenders in paints. In suitable combination with other extenders they enable useful savings to be made in prime pigment and binder costs without affecting the desirable properties of the paint. The presence of whiting reduces the tendency to sediment during storage, prevents the flotation of coloured pigments and assists the development of full tinting power. Although there are limits to its use in acidic conditions it is of some value in anti-corrosive paints because of its neutralizing effect. In the case of organic solvent-based paints the whiting is provided with a surface active coating to aid dispersion. Whitings used in paints generally have a size distribution in the range 30–40% finer than 2 microns, depending on the application.

Polymers

Calcium carbonate is used as a filler in a variety of extruded and moulded rubbers and synthetic rubbers. It does not generally impart any reinforcement and its main function is to economise on the use of more expensive constituents. However, its presence does improve extrusion characteristics and contribute towards hot tear resistance.

In latex compounds used for foam backed carpets, fine limestone is used to give body and compression resistance to the product as well as reduce costs. In plastics, such as PVC, polyester and epoxy resins, fine whitings are used not only as extenders but also to inhibit shrinkage during extrusion or moulding and to improve mechanical properties. To improve dispersion, stearate-coated whitings are used in plastics. The particle size range of whiting fillers used in polymers is generally similar to that used in paints.

Paper

Until approximately twenty-five years ago paper was made under acidic conditions which precluded the use of calcium carbonate. However with the development of neutral or alkaline systems, particularly in Europe and North America, there has been an increase in demand for good quality, low cost calcium carbonate fillers in printing and writing paper to economise on the use of more expensive fibrous materials. The fillers involved are broadly similar to those used in paint and polymers in terms of size and a good standard of colour and brightness is usually required.

For high quality coatings on paper, very fine grades of whiting (80–90% below 2 microns) with exceptional standards of brightness are used. Materials used for this purpose include precipitated calcium carbonate, Italian marble and chalk from East Grimstead, Wilts.

Other uses

Special grades of natural whiting or precipitated material known as Chalk BP (Creta Praeparata) listed in the British Pharmacopoeia, are used in baking, and pharmaceutical products. Under the Flour Order of 1963 all flour except wholemeal and self-raising flour is required to contain 0.23–0.39% calcium carbonate and in a typical recent year, 1975/76, 3.6 million tonnes of flour were produced containing an estimated 11 250 tonnes of calcium carbonate. Small quantities of calcium carbonate are used in toothpastes to provide a mild abrasive and modify the flow characteristics of the paste. It is also used for pH control in the manufacture of antibiotics and in tablets and other medicines. Very fine (2–8 micron) precipitated material is used in face powders.

Because of its mildly abrasive properties calcium carbonate powder is used in various domestic and industrial polishes and scourers such as window polish, car polish and silver polish.

Calcium carbonate is also used as a carrier for several chemicals, fertilizers, herbicides, fungicides and insecticides which are applied in small quantities in agriculture and horticulture. The high surface area of the whiting allows for easy, uniform, absorption of minor amounts of the active chemical, which the fine free-flowing particles can then disperse widely.

Fine grades of precipitated material are used as additives in printing inks, where the thin film of ink laid on paper requires a very fine pigment particle size to give a smooth finish and clear impression. The fine filler controls the flow of the ink, ensures an even spread during printing, and gives a mottle-free lasting film.

Whitings are the essential basis of putty and modelling clays and are also used in linoleum and various mastics and sealants.

Uses abroad

Limestone and dolomite are frequently used abroad in processes not currently carried out on a significant scale in the United Kingdom. Because such processes may operate domestically in future or may attract overseas demand for domestic material, they are briefly described.

Flue-gas desulphurisation

Removal of sulphur dioxide from the flue gases of power stations burning sulphurous coal is carried out on a significant scale in the United States to comply with Federal clean air requirements. The most popular processes involve wet scrubbing using suspensions of limestone or hydrated lime in water. Use of limestone for this purpose is expected to increase, until by 1990 it is estimated that the annual market for limestone and lime will be 3.0 million tonnes and 1.7 million tonnes respectively. Specifications for the limestone usually require 85–95% calcium carbonate, 0–5% magnesium carbonate and less than 5% acid insolubles; while for lime at least 90% calcium oxide and a maximum of 4% silica is usually required. Limestone must be ground to at least 84% passing 44 microns before being fed into the scrubber. The effect of magnesia on performance has not been fully evaluated, but it is by no means entirely deleterious, and in some instances a high magnesium lime is preferred, although where the carbonate is used there tends to be a preference for material with a low magnesia content.

There are many other processes for the removal of sulphur dioxide from gaseous combustion products but few have been employed on a commercial scale. However there is some use of a dry scrubbing process which involves the introduction of finely ground dry lime into the exit gases. Another process involves the addition of dry limestone powder into a fluid bed firing system, but this has been used only in small industrial boilers. In future wet scrubbing systems are expected to predominate.

Pulp and paper

The treatment of pulp to produce paper involves dissolution of the raw material in caustic soda, to release the cellulose, followed by a cellulose bleaching operation. In the Sulphate (Kraft) process, sodium carbonate produced during pulp dissolution is treated with lime to regenerate caustic soda for further use. The total amount of lime used in the operation on a world wide scale is very large (7 million tonnes annually in the USA alone). However, the amount of new lime required is only about 13% of total requirements in the USA, most being recycled.

In addition most plants use calcium hypochlorite for bleaching, which is made by bubbling chlorine into milk of lime solution. ASTM specifications are available which cover the use of lime in pulp treatment and bleaching.

Calcium carbide

Calcium carbide, an important intermediate material in the manufacture of acetylene, is made by heating a mixture of lime and coke at 2000°C according to the reaction, $CaO + 3C \rightarrow CaC_2 + CO$. About one tonne of lime is required for each tonne of carbide produced and ASTM specifications exist which cover the use of lime in the process.

Mineral processing

In flotation, which is a fundamental part of many beneficiation processes, lime is widely used as a cheap reagent for pH control. It may also be of value as an aid to sedimentation in settling ponds and for water clarification.

Non-ferrous metallurgy

Limestone is used as a flux in the smelting of certain non-ferrous metals and dolomite is used as a source of magnesium metal. Magnesium is produced either by the electrolysis of magnesium chloride, which may be derived from sea-water-magnesia or by the silico-thermic reduction of calcined dolomite. In the latter process the high temperature reaction of ferrosilicon with the oxides of calcium and magnesium results in the production of magnesium vapour, which is recovered in a condenser, together with a calcium silicate slag and metallic iron. From 1963 to 1968 a plant using the "Pidgeon" silicothermic process, based on local dolomite, was operated at Hopton, Derbyshire.

STATISTICS

Raw material production

Since the first official statistics of limestone production were collected in 1895, a total of just over 2,500 million tonnes of limestone and dolomite have been extracted in the United Kingdom. Annual production increased fairly steadily from approximately 11 million tonnes at the end of the nineteenth century to 41 million tonnes in 1960, after which it increased rapidly to a peak of 108 million

Table 7 United Kingdom. Production of limestone and dolomite[1] 1895–1980

million tonnes

	Total Production			
	Great Britain	*Northern Ireland*	*United Kingdom*	*Annual average United Kingdom*
1895–1899	54.6	1.4	56.0	11.2
1900–1904	58.1	1.3	59.4	11.9
1905–1909	59.4	1.4	60.8	12.2
1910–1914	59.3	1.2	60.5	12.1
1915–1919	51.2	0.3	51.5	10.3
1920–1924	52.8	0.1	52.9	10.6
1925–1929	68.6	0.3	68.9	13.8
1930–1934	69.6	0.4	70.0	14.0
1935–1939	92.5	0.4	92.9	18.6
1940–1944	101.3	0.6	101.9	20.4
1945–1949	98.2	0.9	99.1	19.8
1950–1954	139.9	1.8	141.7	28.4
1955–1959	167.9	2.6	170.5	34.1
1960–1964	229.4	4.6	234.0	46.8
1965–1969	362.9	7.1	370.0	74.0
1970	88.3	1.6	89.9	
1971	92.6	1.9	94.5	
1972	92.2	2.0	94.2	
1973	106.4	2.0	108.4	
1974	100.7	1.8	102.5	
1975	93.3	1.9	95.2	
1976	87.1	2.1	89.3	
1977	84.1	2.3	86.4	
1978	86.3	2.5	88.8	
1979	89.6	2.6	92.2	
1980[2]	86.9	2.3	89.2	

[1] Includes dolomite and magnesian limestone used for refractory, chemical and other purposes specifically dependent on the high magnesium content.

[2] Only provisional national totals were available at the time of going to press.

tonnes in 1973. More than half of all limestone production has taken place in the last twenty years, largely as a result of the high demand for aggregate in road building and other construction works, although there has been a decline in output since 1973 (Table 7 and Fig 4).

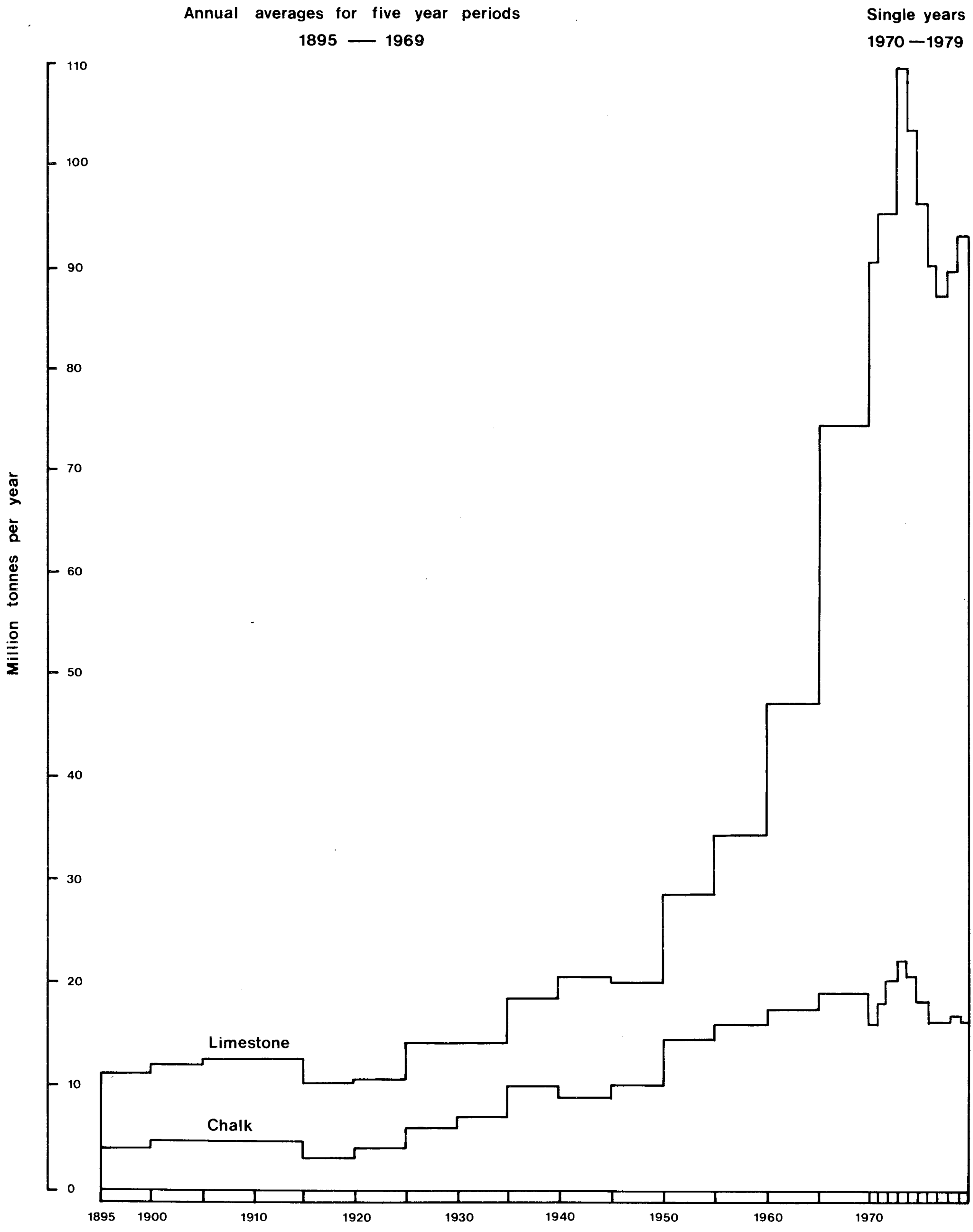


Figure 4 United Kingdom production of limestone and chalk 1895–1979

Since 1895, approximately 800 million tonnes of chalk have been extracted in the United Kingdom. Annual production has increased from approximately 4 million tonnes at the turn of the century to a peak of 22 million tonnes in 1973 from which it has fallen somewhat in recent years (Table 8).

Table 8 United Kingdom. Production of chalk 1895–1980

million tonnes

	Total Production			*Annual average*
	Great Britain	*Northern Ireland*	*United Kingdom*	*United Kingdom*
1895–1899	19.6	–	19.6	3.9
1900–1904	22.4	–	22.4	4.5
1905–1909	23.1	–	23.1	4.6
1910–1914	23.1	0.2	23.3	4.7
1915–1919	12.7	0.8	13.5	2.7
1920–1924	18.3	0.7	19.0	3.8
1925–1929	28.1	1.0	29.1	5.8
1930–1934	34.3	0.9	35.2	7.0
1935–1939	49.0	1.0	50.0	10.0
1940–1944	44.2	1.2	45.3	9.1
1945–1949	48.3	1.3	49.6	9.9
1950–1954	70.4	2.2	72.6	14.5
1955–1959	76.4	3.9	80.3	16.0
1960–1964	83.2	4.4	87.6	17.5
1965–1969	89.5	4.3	93.8	18.8
1970	15.2	0.8	16.0	
1971	17.1	0.6	17.7	
1972	19.4	0.6	20.0	
1973	21.5	0.6	22.1	
1974	19.9	0.6	20.5	
1975	17.3	0.6	17.9	
1976	15.7	0.6	16.3	
1977	15.8	0.5	16.3	
1978	16.3	0.4	16.7	
1979	15.9	0.3	16.3	
1980[1]	13.7	0.3	14.0	

[1] Only provisional national totals were available at the time of going to press.

Table 9 United Kingdom. Production of dolomite[1] 1974–1979

thousand tonnes

<table>
<tr><th></th><th>1974</th><th>1975</th><th>1976</th><th>1977</th><th>1978</th><th>1979</th></tr>
<tr><td>For refractory use</td><td>1,372</td><td>1,279</td><td>1,215</td><td>1,346</td><td>1,334</td><td rowspan="3">2,937</td></tr>
<tr><td>For chemical use</td><td>9</td><td>15</td><td>145</td><td>26</td><td rowspan="2">1,182</td></tr>
<tr><td>For other purposes</td><td>1,206</td><td>1,021</td><td>1,954</td><td>1,183</td></tr>
<tr><td>Total</td><td>2,587</td><td>2,315</td><td>3,314</td><td>2,556</td><td>2,515</td><td>2,937</td></tr>
</table>

[1] Dolomite used for purposes specifically dependent on the high magnesium content, i.e. excluding aggregate purposes.

Source: Business Statistics Office.

Table 10 United Kingdom. Production of limestone[1] by counties 1975–1979

thousand tonnes

	1975	*1976*	*1977*	*1978*	*1979*
Durham, Cleveland	5,187	4,989	4,954	5,323	5,016[2]
Cumbria	4,101	4,344	3,701	4,092	4,423
Northumberland, Tyne & Wear	2,227	2,057	1,781	1,727	1,518[3]
South Yorkshire / Humberside	2,893	2,811 (South Yorkshire / Humberside / West Yorkshire)	2,600	2,672	2,391
West Yorkshire	—		—	—	—
North Yorkshire	7,036	6,877	6,742	6,948	6,870
Derbyshire	16,500	15,454	15,602	15,315	15,704
Leicester, Nottingham	2,759	2,432	2,479	2,544	3,466 (Leicester, Nottingham / Lincoln)
Lincoln	659	729	671	486	
Northampton	616	394	330	380	412
Lancashire	3,755	3,204	3,046	3,458	3,861
Cambridge	663 (Cambridge / Bedford)	459 (Cambridge / Bedford)	379	456	474
Bedford			—	—	—
Kent, East Sussex	600	336	374	464	198
Oxford	1,201	992	1,017	1,092	1,128
Dorset / Wiltshire	410	449	545 (Dorset / Wiltshire / Cornwall)	561 (Dorset / Wiltshire / Cornwall)	649 (Dorset / Wiltshire / Cornwall)
Cornwall	—	—			
Devon	4,170	3,068	3,069	2,865	3,310
Somerset	9,087	8,235	8,110	8,481	8,768
Avon	4,389	3,826	4,075	4,044	4,466
Gloucester	1,409	1,458	1,300	1,329	1,319
Hereford and Worcester / Warwick	846	797	767	885 (Hereford and Worcester / Warwick / West Midlands)	734
West Midlands	—	—	—	—	—
Shropshire	1,541	1,366	1,155	1,369	1,353
Stafford	2,212	2,082	1,914	1,887	2,028
Total England	72,260	66,358	64,612	66,378	68,087
Clwyd	5,900	5,488	4,779	5,330	6,302
Gwynedd	749 (Gwynedd / Powys)	125	93	670 (Gwynedd / Powys)	105
Powys		655	636		691
Mid and West Glamorgan	3,907	3,766	6,157 (Mid and West / South Glamorgan)	6,123 (Mid and West / South Glamorgan)	6,190 (Mid and West / South Glamorgan)
South Glamorgan	1,654	1,841			
Dyfed	2,064	1,960	1,451	1,369	1,434
Gwent	2,277	1,472	1,747	1,768	1,851
Total Wales	16,551	15,307	14,865	15,260	16,573
Scotland	2,222	2,131	2,023	2,201	1,995
Northern Ireland	1,865	2,143	2,316	2,465	2,602
Isle of Man[4]	20	49	65	67	60
Great Britain	91,033	83,797	81,500	83,839	86, 665
United Kingdom	92,898	85,940	83,816	86,304	89,257

[1] Includes dolomite and magnesian limestone used as aggregate and, up to 1978, for agricultural purposes. Excludes dolomite and magnesian limestone used for refractory, chemical and other purposes specifically dependent on the high magnesium content.
[2] excluding Cleveland.
[3] including Cleveland.
[4] excluded from Great Britain and United Kingdom totals.
— nil.
Source: Business Statistics Office.

Production of dolomite and high magnesium limestone has been recorded separately only since 1973 (Table 9). However the data relate only to material specifically used for its magnesium content in applications which include the manufacture of magnesia, refractories, fluxes, and glass making. Dolomite used for aggregate and at least some material used in agriculture is included with limestone.

Geographical details of limestone and chalk production are given in Tables 10 and 11. To preserve confidentiality, totals for some counties are grouped together. Scottish production comes mainly from the Regions of Lothian and Strathclyde (70% in 1978) but, because of the low tonnages involved, a breakdown by Scottish Regions is not included. County breakdowns for Northern Ireland are not published.

The main features of Table 10 are the very high outputs from Derbyshire and the Mendips (shown in the totals for Somerset and Avon). Other important areas include Cumbria, Durham, North Yorkshire, North Wales and South Wales. County outputs for chalk (Table 11) largely reflect the influence of a few large cement works.

Table 11 United Kingdom. Production of chalk by counties 1975–1979 *thousand tonnes*

	1975	*1976*	*1977*	*1978*	*1979*
North Yorkshire, Humberside	2,492	2,126	2,044	1,896	1,948
Lincoln	259	141	263	234	200
Norfolk	}	}	81	74	} 860
Cambridge	} 1,340	} 1,267	} 1,245	} 1,356	}
Suffolk	}	}	}	}	601
Bedford, Buckingham	}	}	}	}	}
Hertford, Oxford	} 2,616	}	}	}	}
Berkshire	}	} 9,769	} 10,316[1]	} 10,848	} 10,486[3]
Kent, Surrey	}	}	}	}	}
Greater London	} 8,496	}	}	}	}
Essex	}	510	}	}	}
East Sussex	} 795	} 700	} 751	} 788	170
West Sussex	}	}	}	}	602
Dorset	19	}	}	}	}
Hampshire, Isle of Wight	} 1,304	} 1,226	} 1,078	} 1,125	} 1,078[2]
Devon, Wiltshire	}	}	}	}	}
Total England	17,320	15,740	15,780	16,321	15,945
Northern Ireland	604	598	473	410	320
United Kingdom	17,924	16,338	16,253	16,731	16,265

[1] Excluding Greater London. [2] Excluding Hampshire and Isle of Wight. [3] Including Hampshire and Isle of Wight.
Source: Business Statistics Office.

Manufactured products and end uses

Since 1974 the Business Statistics Office has published details of limestone and chalk production in Great Britain which include a breakdown by end use and by county or region. The most recent county data are reproduced in Tables 12 and 13. The main features include the outstanding importance of Derbyshire in the production of limestone for industrial purposes and of Northern England and East Anglia in the production of chalk for industrial purposes (lime and whiting).

Table 12 Great Britain. Production of limestone by end-use and county/Scottish region 1978

thousand tonnes

County/Scottish region	*Coated roadstone*	*Uncoated roadstone*	*Concrete aggregate*	*Other constructional uses*	*Agricultural uses*	*Iron and steel and cement*	*Chemical and other non-constructional uses*	*Total*
Cleveland, Durham	192	1,629	160	1.979	260	1,281	32	5,323
Northumberland, Tyne and Wear		679	272	373	123		70	1,727
Cumbria	230	1,123	1,221	806	113	434	166	4,092
Humberside, South Yorkshire	814	1,987	337	200	216	687	246	2,672
North Yorkshire		2,952	855	1,326				6,948
Derby	1,530	2,653	2,320	1,667	234	3,047	3,864	15,315
Lincoln	—	32	13	403	235	—	—	486
Leicester	1	1,160		128		2,484	—	2,544
Nottingham							—	
Northampton	—	79	—	262			—	380
Lancashire	612	671	358	394			37	3,458
Cambridge	—	510	—	91	7	—	118	456
Kent, East Sussex	88		—	106	—	—		464
Oxford	—	71	—	785	26	206	5	1,092
Avon	707	1,474	1,025	804	34	—	—	4,044
Cornwall, Dorset, Wiltshire	—	375	55	92	147	—	82	561
Devon	200	678	893	481		710		2,865
Gloucester	152	292	174	610	62			1,329
Somerset	1,562	1,837	1,865	2,939	29			8.481
Hereford and Worcester	103	293	130	294	—	1,097	103	885
Warwick, West Midlands					—			
Shropshire		592		504	70			1,369
Stafford	249	426		137	51		92	1,887
Total England	6,440	19,513	9,678	14,379	1,608	9,946	4,815	66,378
Clwyd	351	1,407	329	908	74	1,052	1,210	5,330
Dyfed	135	449	216	480	79	—	10	1,369
Mid Glamorgan	206	1,453	1,066	960	30			3,954
South Glamorgan, West Glamorgan	—	478	177	319	—	.... 1,552		2,169
Gwent	119	417	244	870	—			1,768
Powys, Gwynedd	15	373	109	37	56	79	—	670
Total Wales	826	4,576	2,141	3,574	239	...	...	15,260
Highland, Orkney, Western Isles	3	31		14	44			141
Grampian, Tayside, Fife	44	43	62	223	179	.... 1,445		524
Lothian, Strathclyde	24	5		34	50			1,536
Total Scotland	71	79	62	270	273	...	...	2,201
Total Great Britain	7,337	24,167	11,881	18,224[1]	2,120	13,786	6,324	83,839

[1] Includes 149 thousand tonnes of building stone and 1,281 thousand tonnes of railway ballast. ... not available. — nil.

Source: Business Statistics Office.

Table 13 Great Britain. Production of chalk by end-use and county 1978

thousand tonnes

<table>
<tr><th>County</th><th>Cement</th><th>Constructional uses</th><th>Agricultural uses</th><th>Industrial and other uses</th><th>Total</th></tr>
<tr><td>Humberside, North Yorkshire</td><td rowspan="4">2,078</td><td>146</td><td>72</td><td rowspan="4">876</td><td>1,896</td></tr>
<tr><td>Lincoln</td><td>150</td><td>80</td><td>234</td></tr>
<tr><td>Cambridge, Suffolk</td><td rowspan="2">9</td><td>91</td><td>1,356</td></tr>
<tr><td>Norfolk</td><td>58</td><td>74</td></tr>
<tr><td>Bedford, Berkshire
Buckingham, Hertford
Kent, Greater London
Oxford, Surrey
Essex</td><td rowspan="3">11,442</td><td>471</td><td>229</td><td rowspan="3">253</td><td>10,848</td></tr>
<tr><td>East Sussex
West Sussex</td><td>67</td><td>51</td><td>788</td></tr>
<tr><td>Hampshire, Isle of Wight
Devon, Dorset, Wiltshire</td><td>109</td><td>138</td><td>1,125</td></tr>
<tr><td>Total Great Britain (England)</td><td>13,520</td><td>952</td><td>720</td><td>1,128</td><td>16,321</td></tr>
</table>

Source: Business Statistics Office.

National totals of the data on which Tables 12 and 13 are based are available for several additional end uses such as building stone, railway ballast and cement in addition to end use details of lime produced from limestone and chalk. (Tables 14–17).

Table 14 Use of limestone and chalk in construction: Great Britain

thousand tonnes

	1974	*1975*	*1976*	*1977*	*1978*	*1979*
Limestone used for:						
building stone	190	216	360	138	149	164
coated roadstone	9,867	8,960	7,664	7,356	7,337	8,013
uncoated roadstone	31,348	26,866	23,812	23,336	24,167	27,136
railway ballast	1,093	1,448	1,413	1,321	1,281	1,006
concrete aggregate	12,668	12,193	11,218	11,002	11,881	11,359
other construction purposes	17,605	17,959	16,336	16,448	16,794	17,134
Chalk used in construction	1,927	1,450	561	930	952	1,064
Limestone used in cement	10,602	10,076	9,954	9,590	10,242	10,450
Chalk used in cement	16,153	14,272	13,156	13,181	13,520	13,338

Table 15 Use of limestone and chalk in lime making: Great Britain

thousand tonnes

	1974	*1975*	*1976*	*1977*	*1978*	*1979*
Limestone used in calcination	4,362	5,869	5,300	4,933	4,745	4,990
Chalk used in calcination	755	467	934	657	683	...

... not available.

Table 16 Use of limestone, chalk and lime in agriculture: Great Britain

thousand tonnes

	1974	*1975*	*1976*	*1977*	*1978*	*1979*
Limestone used as carbonate	1,078	1,603	1,997	1,854	1,845	1,679
Limestone used as lime[1]	1,137	610	614	269	275	300
Chalk used as carbonate	435	628	683	583	684	606 (chalk as carbonate and as lime combined)
Chalk used as lime[1]	242	85	43	38	36	

[1] Separate statistics on consumption in agriculture were published by the Ministry of Agriculture, Fisheries and Food, based on the lime subsidy which ended in 1976. The MAFF statistics for carbonate consumption were comparable with those in Table 16 but there is a discrepancy in the case of consumption of calcined material.
Source: Business Statistics Office.

Separate statistics of finished cement production are available from 1945 (Table 18), and of deliveries by planning region for the last five years (Table 19). In addition to the official statistics (Table 17), the Iron and Steel Industry also produce statistics showing the consumption of limestone, dolomite and lime in blast-furnaces and steel furnaces in the United Kingdom (Table 20).

Table 17 Industrial and other non-construction uses of limestone, chalk and lime: Great Britain

thousand tonnes

	1974	*1975*	*1976*	*1977*	*1978*	*1979*
Iron and steel manufacture:						
limestone used as carbonate	2,662 (carbonate and lime combined)	2,393	2,298	2,135	1,735	1,709
limestone used as lime		1,226	1,606	1,784	1,809	2,048
Chemicals:						
limestone used as carbonate	2,195 (carbonate and lime combined)	672	622	651	769	865
limestone used as lime		1,812	1,871	1,900	1,831	1,797
Building materials:						
limestone used as carbonate	... (carbonate and lime combined)	1,737	1,798	1,721	1,875	1,166
limestone used as lime		458	451	224	225	202
Other purposes						
limestone used as carbonate	3,243 (carbonate and lime combined)	1,041	1,024	1,013	1,019	984
limestone used as lime		1,763	758	756	605	643
Chalk used for industrial and other purposes as carbonate	669	504	406	429	481	937 (chalk as carbonate and as lime combined)
Chalk used for industrial purposes as lime	513	382	891	619	647	

... not available.

Source: Business Statistics Office.

Table 18 United Kingdom. Production of cement 1945–1980

thousand tonnes

1945	4,116	1963	14,061
1946	6,680	1964	16,972
1947	7,072	1965	16,977
1948	8,658	1966	16,792
1949	9,364	1967	17,617
1950	9,909	1968	17,940
1951	10,356	1969	17,460
1952	11,317	1970	17,171
1953	11,398	1971	17,697
1954	12,152	1972	18,048
1955	12,714	1973	19,986
1956	12,968	1974	17,781
1957	12;154	1975	16,891
1958	11,853	1976	15,780
1959	12,793	1977	15,457
1960	13,501	1978	15,916
1961	14,375	1979	16,140
1962	14,255	1980	14,805

Source: Department of Environment, Housing and Construction Statistics.

Table 19 Deliveries of cement by planning region[1]

thousand tonnes

	1974	*1975*	*1976*	*1977*	*1978*	*1979*
Northern	1,105	985	895	829	828	778
North West	1,728	1,462	1,370	1,285	1,328	1,325
Yorkshire & Humberside	1,255	1,268	1,146	1,092	1,143	1,144
West Midlands	1,503	1,414	1,314	1,201	1,269	1,308
East Midlands	1,319	1,263	1,319	1,135	1,222	1,239
East Anglia	790	702	630	697	713	695
South East	5,091	4,668	4,236	3,911	4,009	4,136
South West	1,445	1,410	1,302	1,187	1,225	1,309
Total England	14,236	13,172	12,212	11,337	11,737	11,934
Wales	960	917	980	836	872	935
Scotland	1,477	1,738	1,498	1,367	1,333	1,307
Total Great Britain	16,673	15,827	14,616	13,541	13,942	14,177

[1] Invoiced sales plus imports.

Source: Department of Environment, Housing and Construction Statistics.

Table 20 Limestone, lime and dolomite consumption in blast-furnaces, sinter plants and steel furnaces 1969–1979

thousand tonnes

	1969	*1970*	*1971*	*1972*	*1973*	*1974*	*1975*	*1976*	*1977*	*1978*	*1979*
Limestone:											
Blast-furnace & sinter plants	1,933.5	2,313.9	2,072.6	2,023.1	2,291.4	1,784.8	1,735.1	1,776.6	1,487.4	1,399.3	1,089.6
Steel furnaces	780.5	701.8	570.0	479.9	518.1	302.9	280.3	333.9	252.1	106.3	116.2
Dolomite:											
Blast-furnace & sinter plants	516.5	523.9	454.8	391.5	445.7	468.4	299.5	516.5	642.7	647.0	858.7
Steel furnaces	245.3	246.1	186.2	166.1	156.6	94.9	89.6	150.3	192.2	182.5	323.2
Lime:											
Steel furnaces	1,382.8	1,468.0	1,254.0	1,396.1	1,531.6	1,250.6	1,204.6	1,287.6	1,174.5	1,227.0	1,322.6
Iron[1]	16,653	17,672	15,416	15,316	16,838	13,903	12,131	13,835	12,232	11,434	12,898
Steel[2]	26,822	28,291	24,153	25,293	26,594	22,323	20,098	22,274	20,411	20,311	21,464

[1] Production in blast-furnaces.
[2] Crude steel production.
Source: Iron and Steel Statistics Bureau.

Overseas trade

Overseas trade is summarised in Table 21. Details of the country of origin of imports and destination of exports are given in Tables 22–29.

The main features of the import trade include high purity dolomite from Spain and Norway, used in the manufacture of special glass, the iron content of which is generally an order of magnitude lower than that found in domestic material.

In addition there are imports of high purity marble from such places as Carrara, Italy, for industrial use in glass making or high whiteness fine powders. However, the data is grouped with that relating to other types of crushed stone and is not identifiable as limestone, although the importance of Italian marble for building and ornamental purposes is clear from Table 23. Importation of cement is of little importance nationally and relates essentially to material transported from the Irish Republic to Northern Ireland.

Table 21 United Kingdom trade in limestone and limestone based products

	thousand tonnes				*£ thousand*			
	1977	*1978*	*1979*	*1980*	*1977*	*1978*	*1979*	*1980*
Chalk								
Imports	1.1	1.0	1.5	0.6	60	82	126	108
Exports	58.5	60.4	60.3	57.7	1,883	2,131	2,535	2,633
Cement								
Imports								
Portland cement clinker	—	—	3.9	14.1	—	—	213	753
Portland cement	47.5	100.2	136.3	91.9	901	2,016	2,759	1,935
Aluminous cement	3.8	2.6	4.2	2.2	693	440	721	351
Other cement	2.3	4.4	2.5	10.0	177	273	248	675
Exports								
Portland cement clinker	557.3	667.8	406.5	176.9	6,225	8,815	6,108	2,646
Portland cement	1,118.3	1,174.7	1,163.5	814.8	17,994	20,078	20,683	17,586
Aluminous cement	19.4	22.5	18.3	21.1	1,607	2,323	1,923	2,514
Other cement	16.6	14.5	12.1	12.6	1,230	1,616	1,487	1,987
Dolomite								
Imports	52.3	95.2	80.2	64.3	1,081	1,534	1,603	1,458
Exports	3.7	12.1	27.3	30.1	207	524	1,162	1,385
Marble (Building & monumental, unworked)								
Imports	13.0	12.6	9.1	9.0	1,595	1,628	1,541	1,687
Exports	0.0	0.0	0.0	0.1	1	1	2	4
Lime (Quick, Slaked, Hydraulic)								
Imports	2.5	2.7	2.7	1.4	64	78	92	56
Exports	47.0	40.5	42.4	32.7	2,837	2,398	2,068	2,153
Limestone Flux								
Imports	5.7	3.1	3.5	2.7	101	78	90	81
Exports	14.3	356.3	867.7	799.1	228	832	2,002	2,074

— nil.

Source: HM Customs & Excise.

Table 22 United Kingdom imports of dolomite 1977–1980

Country of Consignment	*1977*		*1978*		*1979*		*1980*	
	'000 tonnes	*£'000 cif*	*'000 tonnes*	*£'000 cif*	*'000 tonnes*	*£'000 cif*	*'000 tonnes*	*£'000 cif*
Belgo-Lux	0.5	24	0.3	10	3.6	135	0.1	3
Germany, Fed. Rep.	1.5	142	1.4	143	1.1	120	0.8	104
Norway	12.1	474	12.4	496	13.6	532	14.9	638
Spain	37.8	417	80.4	850	61.2	761	46.3	640
Sweden	0.5	20	0.7	29	0.1	2	0.1	2
USA	0.0	4	0.0	3	0.1	8	0.1	8
Other countries	0.0	0	0.0	3	0.5	45	2.0	63
Total from EEC	2.0	166	1.7	154	4.7	260	2.5	135
Total	52.3	1,081	95.2	1,534	80.2	1,603	64.3	1,458

Source: HM Customs & Excise

Table 23 United Kingdom imports of unworked building and ornamental marble and other calcareous stone 1977–1980

Country of Consignment	*1977*		*1978*		*1979*		*1980*	
	'000 tonnes	*£'000 cif*	*'000 tonnes*	*£'000 cif*	*'000 tonnes*	*£'000 cif*	*'000 tonnes*	*£'000 cif*
Belgo-Lux	0.0	17	0.1	12	0.1	15	0.0	10
France	0.1	32	0.1	26	0.2	46	0.1	19
Greece	0.1	17	0.1	21	0.2	21	0.0	4
Irish Republic	0.2	21	0.2	20	0.1	23	0.1	9
Italy	12.1	1,468	10.1	1,368	8.3	1,282	8.3	1,574
Morocco	0.1	6	—	—	—	—	—	—
Portugal	0.3	17	0.3	33	0.1	8	0.1	22
Other countries	0.1	17	1.7	148	0.1	146	0.4	49
Total from EEC	12.5	1,545	10.5	1,432	8.8	1,383	8.5	1,619
Total	13.0	1,595	12.6	1,628	9.1	1,541	9.0	1,687

Source: HM Customs & Excise

Table 24 United Kingdom imports of Portland cement 1977–1980

Country of Consignment	*1977*		*1978*		*1979*		*1980*	
	'000 tonnes	*£'000 cif*	*'000 tonnes*	*£'000 cif*	*'000 tonnes*	*£'000 cif*	*'000 tonnes*	*£'000 cif*
Belgo-Lux	—	—	0.8	28	3.0	111	0.0	2
France	—	—	0.8	25	0.1	7	—	—
Irish Republic	46.2	866	98.6	1,962	133.1	2,639	91.6	1,917
Norway	1.3	35	—	—	—	—	—	—
Other countries	0.0	0	—	—	0.0	1	0.2	16
Total from EEC	46.2	866	100.2	2,016	136.2	2,758	91.7	1,929
Total	47.5	901	100.2	2,016	136.2	2,758	91.9	1,935

— nil.

Source: HM Customs & Excise

Exports of limestone are mainly in the form of material from North Wales, some of which is used for flux (Table 25). There is also a significant export trade in chalk (Table 26), most of which is in the form of whiting, and some exports of lime (Table 27). Worldwide exports of cement in the form of clinker or finished cement far exceed imports and account for very approximately 10 per cent of UK production (Tables 28 and 29).

Table 25 United Kingdom exports of limestone flux 1977–1980

Country of Destination	*1977*		*1978*		*1979*		*1980*	
	'000 tonnes	*£'000 fob*	*'000 tonnes*	*£'000 fob*	*'000 tonnes*	*£'000 fob*	*'000 tonnes*	*£'000 fob*
Belgo-Lux	2.9	17	130.5	204	244.6	424	231.3	453
Denmark	0.0	2	18.9	44	50.8	120	50.8	128
Germany, Fed. Rep.	0.0	2	57.5	128	207.9	469	227.2	560
Irish Republic	4.9	72	6.7	100	7.6	112	9.5	131
Netherlands	0.0	1	12.6	21	37.6	62	15.8	27
Nigeria	1.8	58	1.3	78	1.7	183	3.1	148
Norway	1.3	17	80.7	137	202.7	358	179.4	372
Sweden	1.0	28	42.8	90	103.2	217	74.5	196
Other countries	2.4	31	5.3	30	11.6	57	7.5	59
Total to EEC	9.0	96	229.1	503	556.7	1,208	537.2	1,306
Total	14.3	228	356.3	832	867.7	2,002	799.1	2,074

Source: HM Customs & Excise

Table 26 United Kingdom exports of chalk 1977–1980

Country of Destination	*1977*		*1978*		*1979*		*1980*	
	'000 tonnes	*£'000 fob*	*'000 tonnes*	*£'000 fob*	*'000 tonnes*	*£'000 fob*	*'000 tonnes*	*£'000 fob*
Australia	7.3	251	7.4	287	8.3	362	6.3	308
Finland	6.1	87	3.4	55	3.0	52	4.1	94
Ghana	0.8	25	1.5	86	0.0	3	0.1	7
Irish Republic	6.4	169	6.1	177	3.6	118	2.1	94
Jordan	2.3	79	2.8	94	2.8	109	1.3	54
Nigeria	7.6	285	6.2	282	8.0	392	9.9	606
Portugal	1.4	46	1.3	51	1.1	51	1.5	66
Saudi Arabia	2.4	75	4.0	112	1.5	63	2.0	68
Singapore	1.0	49	1.1	59	2.3	137	1.6	109
South Africa	0.7	26	1.5	54	1.1	55	1.3	72
Sweden	3.1	77	10.8	329	11.2	449	12.6	409
USA	1.4	56	1.9	57	1.4	52	1.4	77
Other countries	18.0	658	12.4	488	16.0	692	13.5	669
Total to EEC	7.8	217	7.2	220	4.6	162	3.5	169
Total	58.5	1,883	60.4	2,131	60.3	2,535	57.7	2,633

Source: HM Customs & Excise

Table 27 United Kingdom exports of lime 1977–1980

Country of Destination	*1978*		*1979*		*1980*			
	'000 tonnes	*£'000 fob*	*'000 tonnes*	*£'000 fob*	*'000 tonnes*	*£'000 fob*	*'000 tonnes*	*£'000 fob*
Ghana	1.5	70	2.5	123	1.5	69	2.8	160
Guyana	3.2	144	2.4	125	1.6	87	3.8	225
Iran	1.1	51	0.6	24	0.6	27	0.6	33
Irish Republic	1.9	49	1.0	31	1.6	66	1.8	112
Liberia	0.3	34	0.3	29	0.3	37	0.1	10
Nigeria	26.8	1,997	13.8	1,232	5.4	362	7.7	813
Norway	1.0	32	0.1	6	0.1	6	0.3	19
Portugal	1.8	39	0.8	22	0.9	26	1.1	33
Sudan	0.9	28	0.9	2	2.6	102	3.1	146
Trinidad & Tobago	0.5	38	0.6	53	0.4	33	1.3	60
Venezuela	—	—	9.3	352	18.3	816	3.5	184
Other countries	8.0	355	8.2	399	9.1	437	6.6	358
Total to EEC	2.9	95	1.6	73	2.4	115	2.1	143
Total	47.0	2,837	40.5	2,398	42.4	2,068	32.7	2,153

— nil.
Source: HM Customs & Excise

Table 28 United Kingdom exports of Portland cement 1977–1980

Country of Destination	*1977*		*1978*		*1979*		*1980*	
	'000 tonnes	*£'000 fob*	*'000 tonnes*	*£'000 fob*	*'000 tonnes*	*£'000 fob*	*'000 tonnes*	*£'000 fob*
Bahrain	0.3	26	4.0	215	0.1	14	0.2	25
Gambia	10.2	230	6.3	158	2.8	81	0.9	36
Iraq	—	—	17.1	382	—	—	—	—
Iran	24.5	598	16.5	412	0.1	6	0.0	1
Irish Republic	24.3	727	30.9	1,106	19.6	824	22.3	1,146
Mauritius	—	—	13.2	169	—	—	—	—
Nigeria	716.8	10,942	644.1	10,229	495.7	7,898	575.7	11,328
Saudi Arabia	6.2	694	3.6	446	39.9	1,173	6.1	964
Sudan	13.1	303	1.1	34	2.2	69	1.2	41
USA	78.7	1,109	234.2	3,492	423.3	6,944	188.9	3,024
Venezuela	223.6	2,563	181.1	2,533	163.0	2,906	—	—
Other countries	20.6	829	22.6	902	16.8	768	19.5	1,021
Total to EEC	26.8	835	33.9	1,225	21.2	898	25.9	
Total	1,118.3	17,994	1,174.7	20,078	1,163.5	20,683	814.8	17,586

— nil.
Source: HM Customs & Excise

Table 29 United Kingdom exports of Portland cement clinker 1977–1980

Country of Destination	*1977*		*1978*		*1979*		*1980*	
	'000 tonnes	*£'000 fob*	*'000 tonnes*	*£'000 fob*	*'000 tonnes*	*£'000 fob*	*'000 tonnes*	*£'000 fob*
Benin	—	—	63.3	674	—	—	—	—
Gabon	68.3	753	33.6	428	—	—	—	—
Irish Republic	—	—	97.6	1,358	69.5	1,097	73.3	1,174
Kuwait	—	—	32.3	424	—	—	—	—
Nigeria	49.6	549	26.2	338	—	—	—	—
Togo	200.6	2,068	272.8	3,721	54.8	846	35.0	548
USA	108.6	1,357	139,1	1,832	273.3	4,034	25.3	363
Other countries	130.2	1,498	2.9	40	8.9	131	43.3	561
Total to EEC	24.5	313	97.6	1,358	69.5	1,098	73.3	1,174
Total	557.3	6,225	667.8	8,815	406.5	6,108	176.9	2,646

— nil.

Source: HM Customs & Excise

Production by geological system

An estimate of the proportions of total limestone, dolomite and chalk produced from various geological systems in 1977 is given in Table 30. The table is related to a total production of 102.7 million tonnes and illustrates the overwhelming importance of the Carboniferous and the large quantity of chalk from the Cretaceous, used mainly for cement manufacture. Materials such as vein calcite and shell sand are not considered because of the negligible quantities involved.

Table 30 United Kingdom production of limestone, dolomite and chalk by geological system, 1977

	%
Cretaceous	16.1
Jurassic	6.4
Permian	11.5
Carboniferous	61.5
Devonian	2.4
Silurian	1.5
Cambrian/Ordovician, Precambrian	0.6
	100.0

RESOURCES AND EXPLOITATION

Workable deposits occur at many horizons in the United Kingdom and by any international standard the country is well endowed with limestone resources. However, because of the thickness, quality and consistency of the material and the convenient location of most outcrops, exploitation is concentrated on Carboniferous limestone which now accounts for over 60% of production. Other formations of industrial importance in terms of output include Magnesian Limestone, Chalk, certain Jurassic limestones and Devonian limestone in south west England (Table 30).

In contrast to the rest of the United Kingdom, Scotland posesses few limestone resources, and these have already been described systematically (Special Reports on the Mineral Resources of Great Britain, Vol 35, Limestones of Scotland, HMSO 1949). Until recently limestone resources elsewhere were regarded as sufficiently abundant to meet foreseeable needs. However, the Institute of Geological Sciences has now begun a detailed assessment of Carboniferous limestones in specific areas in England and Wales in response to increased land use pressures. United Kingdom resources of dolomite were last described in a special survey carried out in the 1914–18 war.

In the following description resources of economic or potential economic importance are described, in order of geological age, and workings known to be active since 1978 are recorded:

Precambrian

The Lewisian in north-west Scotland contains occasional small lenses of calcareous material in hard crystalline schists and gneisses. The limestones have been highly altered and some of the calcium and magnesium has combined with siliceous material to form metamorphic minerals such as forsterite, diopside and tremolite. However the material is of little economic importance as it is relatively impure, most of the sites are in remote areas, there are no active workings and the geology is such that quarrying conditions would be difficult. The more important outcrops occur around Loch Maree, Loch Gairloch, Loch Duich and Gleneig in Highland Region. In Coll, Tiree and Iona there are some deposits of ornamental marble which were once worked and in south Harris there are some lenticular beds of crystalline limestone.

Moine

The Moine rocks of Scotland and Northern Ireland contain very little limestone. A few small outcrops have been recorded in the Highland Region, principally at Shiness on Loch Shin, at Rebeg, south-west of Inverness, and near Kincraig. Small limestone outcrops within Moine terrain also occur at Glen Urquhart and Foyers, Highland Region.

Dalradian

Although the upper part of the Dalradian succession includes Lower Palaeozoic rocks the whole assemblage is included with the Precambrian for the purposes of this description.

Dalradian rocks in the Central Highlands of Scotland, Shetland and Northern Ireland contain beds of limestone, metamorphosed to a greater or lesser extent, which vary in thickness from a few centimetres up to several metres (Figure 5). Depending on the grade of metamorphism and the original composition, metamorphic calc-silicate minerals may be present, the original calcite may be recrystallised and dolomite may be dissociated into calcite and periclase (MgO).

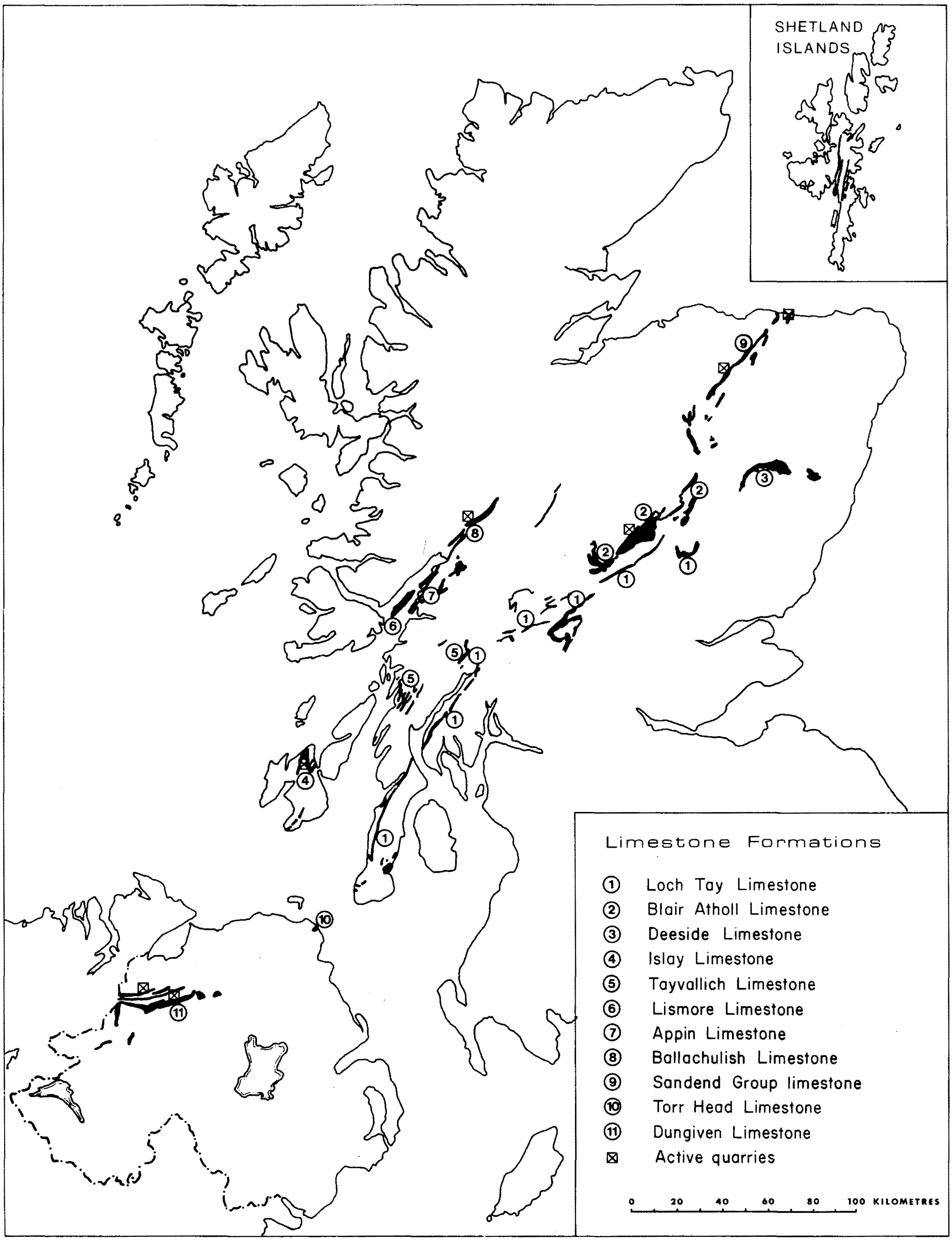


Figure 5 Distribution of Dalradian limestones

Analyses published by Robertson suggest that Dalradian limestones in Scotland may contain up to 97% $CaCO_3$ although much lower values are usual. They also tend to contain up to 5% magnesium carbonate; larger amounts are unusual and dolomite occurs only in the Appin Limestone.

In Shetland, limestone reserves, which are fairly extensive, occur in three main zones some 20 km long by 0.5 to 1.0 km wide. Within each zone the limestones occur in lenticular, nearly vertical, masses, which sometimes contain interbedded schists. Calcium carbonate content is in the range 80–90%.

In Moray, Grampian Region, limestone beds separated by black schists are well developed in the Sandend Group of the Dalradian which extends south-eastwards over a distance of some 75 km from Portsoy on the Moray Firth to near Inchory. At a stratigraphically higher level the Boyne Bay limestone is also of importance on the coast near Banff.

The Deeside limestone outcrops fairly extensively around Banchory and Aboyne in Grampian Region. However such analyses as are available suggest that the material is impure, and there are no active workings.

In Tayside the Blair Atholl Limestone is well developed around the town of that name. Discontinuous outcrops of the Loch Tay Limestone extend from near Spittal of Glenshee in a south easterly direction around Loch Tay, to Crianlarich, Central Region. Beyond Crianlarich the Loch Tay Limestone forms a long narrow outcrop extending through Glen Fyne to Campbeltown in Strathclyde.

Elsewhere in Strathclyde, limestones are of importance in the Isle of Islay, and on the mainland the Tayvallich limestones outcrop in the area around Loch Awe.

In Loch Linhe the island of Lismore is composed almost entirely of limestone and on the south-east shore the dolomitic Appin Limestone is present. To the north-east the Ballachulish limestone extends from the entrance to Glencoe to Spean Bridge in the Great Glen.

In Northern Ireland, Dalradian rocks similar to those found in Scotland occur in a small outcrop at Torr Head, north-east Antrim and over a much wider area in western Londonderry, Tyrone and north Fermanagh, centred on the Sperrin Mountains. In this area the Dungiven Limestone Group, consisting of bands and lenticles of limestone with interbedded biotite-schists, extends through the area between Dungiven and Newtownstewart, together with subsidiary limestone units.

As Dalradian limestone usually occurs in vertical or steeply dipping deposits, seldom more than 100 m wide, bench faces in quarries are of restricted length and there are obvious difficulties in achieving high outputs from many of the sites.

In Scotland the more important producers are located at Fort William, Dufftown, Blair Atholl and Kirkmichael (Tayside), with smaller quarries in Islay and at Portsoy on the Moray Firth. Most of the quarries have extensive grinding equipment for the production of agricultural limestone and asphalt filler, usually their main products in an area otherwise devoid of such materials. However the production of aggregates, including coated roadstone, is important at Blair Atholl and to a lesser extent at Kirkmichael.

In Northern Ireland there are only two quarries in the Dalradian. They produce ground limestone for agriculture and some aggregate.

Although some quarries work a relatively impure limestone with a silica content in excess of 10%, others produce material with a relatively high calcium carbonate content. Because of the presence of metamorphic minerals some of the less pure Dalradian limestones can develop good Polished Stone Values and Aggregate Abrasion Values which makes them suitable for use in the surfacing of major highways (Table 31). In this respect they are probably unique among limestones in the United Kingdom.

Table 31 Properties of limestone from selected quarries in the Dalradian

	Torlundy Quarry [1] *(Fort William)* %	*Wester Bleaton Quarry* [2] *(Kirkmichael)* %
$CaCO_3$	99–93	70.5
$MgCO_3$	2.2–1.0	3.8
SiO_2	1.0–2.5	18.2
Fe_2O_3	0.2–0.8	2.1
Al_2O_3	—	5.4
TiO_2	—	0.3
K_2O	—	1.0
Aggregate Crushing Value	—	23
Aggregate Abrasion Value	16.4	10
Aggregate Impact Value	—	22
Polished Stone Value	45–47	59

Sources: [1] Highland Lime Co Ltd.
[2] W. T. Bathgate Ltd.

Cambrian and Ordovician

The Durness Limestone in north-west Scotland is mainly of Cambrian age, although it extends into the Lower Ordovician. The formation crops out in Skye and at irregular intervals on the mainland between Loch Kishorn and Durness (Figure 6). It consists, for the most part, of dolomite or dolomitic limestone containing up to approximately 10 per cent magnesium carbonate. In some areas thermal metamorphism has produced marble or brucite-marble, for example, on Skye and near Elphin, Sutherland.

The Durness Limestone is worked only at Ullapool and on Skye. The quarry at Ullapool produces a dolomite containing approximately 42% $MgCO_3$ and 5–8% SiO_2, which is mainly sold for agricultural purposes throughout northern Scotland, although material is also produced for concrete aggregate and roadstone to satisfy the limited local demand. In Skye thermally metamorphosed Durness Limestone known as Skye Marble or Torrin Marble is worked at Torrin. The material is a white dolomite containing 43.5% $MgCO_3$ which until recently was used exclusively for external aggregate work (p 28). The deposit contains irregular intrusions of dolerite which must be extracted together with the marble. A high grade white coloured marble is subsequently produced by separating the coarse material according to its colour by means of an optical sorting machine.

South-east of Girvan, in southern Strathclyde, the Ordovician Stinchar Limestone is exposed in a series of discontinuous outcrops in steeply dipping and folded strata. Bulk analyses which suggest a calcium carbonate of 87% together with 3% magnesium carbonate are probably typical. At present it is quarried only at Tormitchell, near Girvan as a byproduct of a greywacke working and is largely used for agricultural purposes.

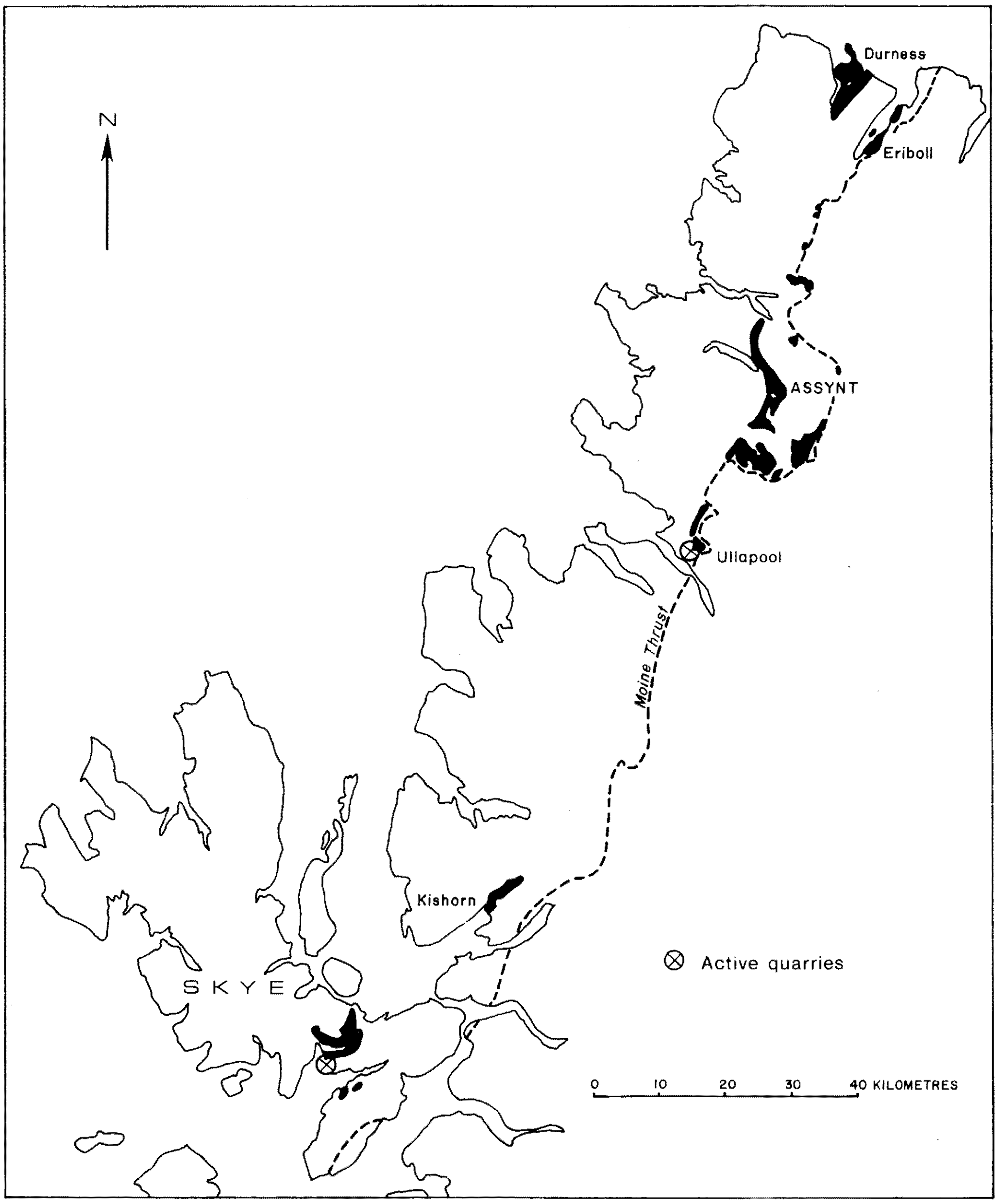


Figure 6 Distribution of Durness Limestone in north-west Scotland

In Cumbria, the Coniston Limestone Group includes calcareous mudstones together with thin impure limestone bands. The Group extends across the Lake District and is present in the Cautley and Cross Fell Inliers, but contains no active workings.

In Dyfed some impure Ordovician limestones are present in the area between St Clears and Haverfordwest.

Silurian

In the Welsh Borders and parts of the Black Country the Wenlock and Ludlow Series contain up to three main limestone formations known as the Woolhope, Wenlock and Aymestry limestones (Figure 7).

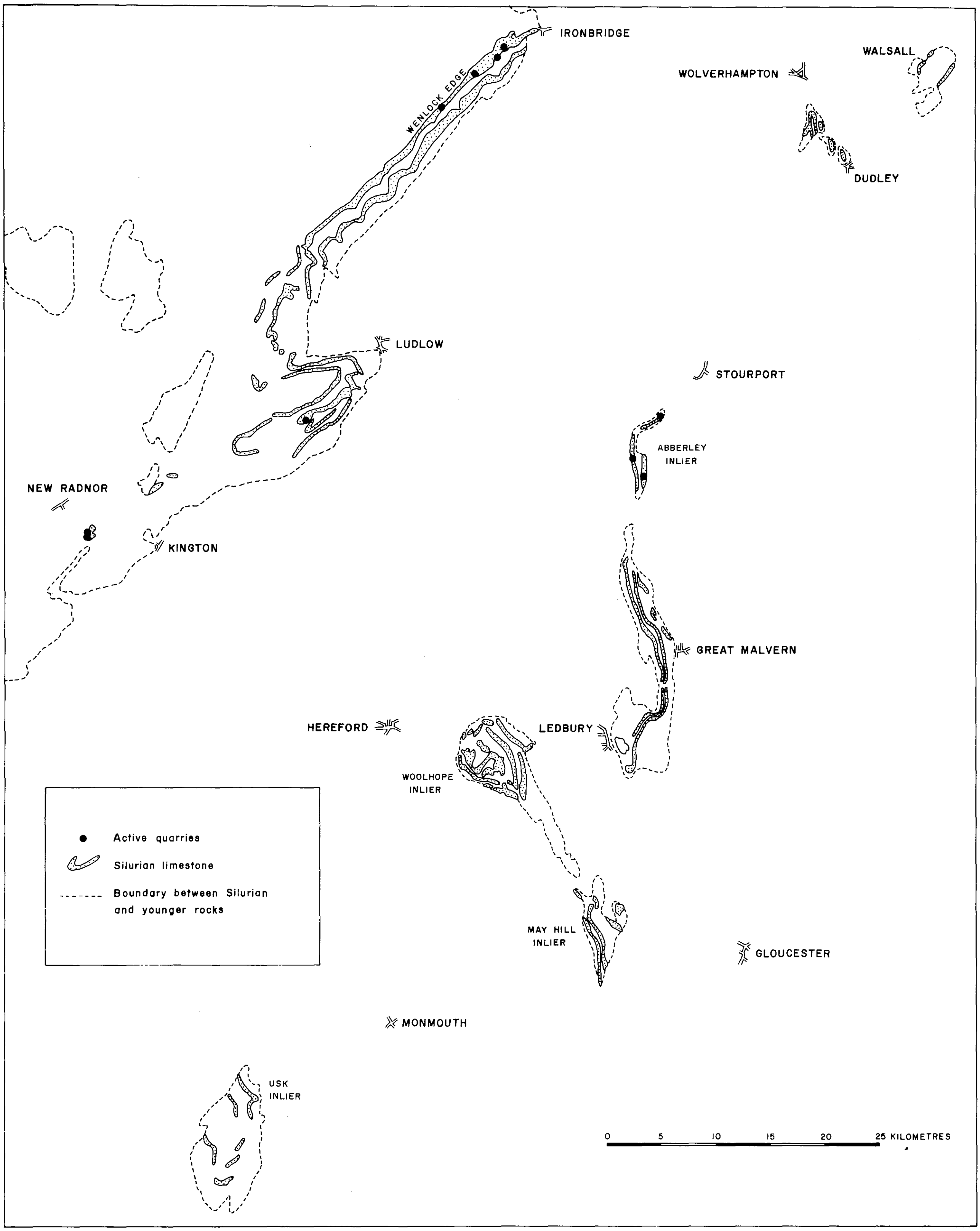


Figure 7 Distribution of Silurian limestones in the Welsh Borders

Individual limestones vary in thickness and sometimes develop argillaceous bands. For example the Wenlock Limestone is approximately 30m thick along Wenlock Edge, but to the south-west near Leintwardine it is represented by 137m of interbedded calcareous and argillaceous material, while at Usk it is only

12m thick. Elsewhere similar variations in all the limestones are common, the Woolhope Limestone being absent altogether in the Wenlock Edge area.

Exploitation of Wenlock Limestone takes place at the north-east end of Wenlock Edge in four main quarries. However, the presence of irregular bands of mudstone has an adverse effect on the physical properties of the limestone and largely confines its use to the fields of fill, hardcore and agriculture. In the past, Wenlock Limestone was worked intensively in the Black Country for metallurgical flux, but the local smelting industry is now defunct and the composition is such that these limestones would probably not now be used for this purpose.

In the Abberley area there are two workings in the Aymestry Limestone and one in the Wenlock Limestone. Interbedded non-calcareous material again modifies the properties of the limestone aggregate which is used for fill. In some instances the PSV may be relatively high, but a poor AAV prevents its general use for roadstone (Table 32).

The Aymestry Limestone is also worked at Leinthall Earls, south-west of Ludlow, but the product is essentially a calcareous shale and calcareous siltstone rather than limestone.

The only workings in Woolhope Limestone are at Walton, near Kington where a massive development of algal limestone, known locally as the Dolyhir Limestone, rests uncomfortably on Precambrian greywackes. Two adjacent quarries work the limestone and the underlying greywackes. In this area the limestone, which contains 97% calcium carbonate, is free from shaly material and makes a good quality aggregate suitable for use with bitumen and in concrete (Table 32).

Table 32 Properties of material from selected quarries in the Silurian

	Dolyhir and Strinds [1] *Quarries (Dolyhir Limestone)*	*Woodbury Quarry* [2] *(Aymestry Limestone)*
$CaCO_3$	97.14	—
MgO_3	0.42	—
SiO_2	1.00	—
Al_2O_3	0.37	—
Fe_2O_3	0.14	—
S	0.02	—
LOI	43.80	—
PSV	38	64
ACV	27.4	22
AIV	27.1	24
AAV	23.2	18.5
Water Absorption	0.43	1.43
Crushing strength (MN/m^2)	132	—

Sources: [1] Nash Rocks Stone and Lime Co. Ltd.
[2] Amey Roadstone Corporation.

Devonian

Devonian limestones are of commercial significance only in South Devon, in the area between Plymouth, Torquay and Exeter (Figure 8).

Originally the limestones were probably in the form of disconnected lenticular reef-like bodies, for the most part surrounded by argillaceous sediments.

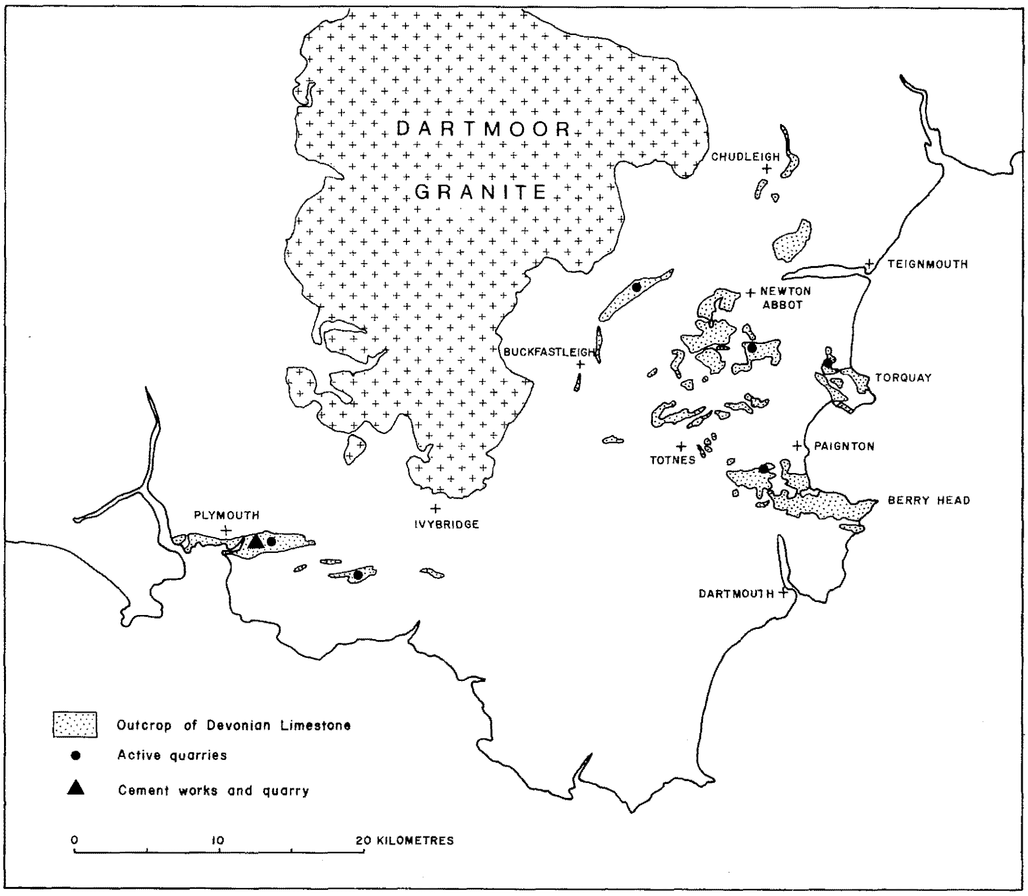


Figure 8 Distribution of Devonian limestone in South Devon

Subsequently the area became involved in very intense earth movements which folded the strata and in many places caused differential movement between the more rigid limestones and the adjacent more plastic shales. Consequently the limestones now occur as isolated blocks with fault margins. Within individual blocks the rock is often steeply dipping, folded or inverted and occasionally there are signs of an incipient cleavage. It is therefore difficult to make realistic estimates of the thicknesses of the limestones although in general the outcrops are sufficiently extensive to sustain large-scale quarrying operations to conventional depths. Calcite veins, iron staining and areas of dolomitisation are fairly common.

The chemical quality of the limestones is such that calcium carbonate contents of up to 97.5% are often maintained in quarry products but very high grade material is not produced (Table 33). Dolomite occurs sporadically, but is easily recognised and can be selectively removed during quarrying operations. Dolomite as a separate commodity is not produced, although one quarry has marketed small amounts of dolomitic limestone for agricultural purposes.

At Plymstock, where limestone and local Devonian shales are worked on adjacent sites for the production of cement, the limestone is produced either in the form of "high grade" (94.1% $CaCO_3$) or "transitional" (81.0% $CaCO_3$) material and appropriate quantities are mixed with shale to produce a kiln feed containing 76–77% $CaCO_3$. To correct an overall silica deficiency, small additions are made of quartz waste from china clay operations.

Devonian limestone forms high quality aggregate and most quarries are concerned essentially with the production of roadstone and concrete aggregate for local use. Some coarse material finds an outlet as undressed stone, used mainly in walling, and some fine material is sold for agricultural purposes and, to a lesser extent, for animal feedstuffs. Polished limestone, such as "Ashburton Marble", is no longer produced.

In the past, limestone from coastal quarries at Berry Head and Hopes Nose, Torquay, was loaded directly into ships, but coastal movement is now confined to relatively small quantities of aggregate from Moorcroft Quarry, Plymouth, and of cement from the Plymstock Works.

Elsewhere, limestone beds in the Devonian are thin and impure. For example in north Devon the Ilfracombe Slates of Exmoor contain thin limestones less than 1m thick and on the Welsh Borders the Old Red Sandstone contains thin impersistent limestones known as "cornstones". In Scotland, where limestones are scarce, irregular "cornstones" in the Upper Old Red Sandstone locally up to 10m thick have been quarried and mined underground principally near Cumnock and Maybole, Strathclyde. Similar "cornstones" have been worked at Cothall near Forres and at Elgin. There are some impure calcareous beds in the Middle Old Red Sandstone in Caithness and Orkney, one of which, a calcareous siltstone, is worked (1979) near Kirkwall for fill and hardcore.

Table 33 Properties of material from selected quarries in Devonian limestone in south Devon

	Moorcroft[1] *(Plymouth)*	*Stoneycombe*[1] *(Newton Abbot)*	*Linhay Hill*[2] *(Ashburton)*
$CaCO_3$	96.1	97.3	93.9
$MgCO_3$	2.0	1.0	1.9
SiO_2	0.6	0.5	2.9
Al_2O_3	1.1	0.2	0.2
Fe_2O_3	0.7	0.2	0.1
ACV	26	24	21
AIV	22	17	16
AAV	15.1	11.8	11.6
PSV	41	41	–
Water Absorption	0.36	0.37	–
Crushing strength MN/m^2	–	–	122

Sources: [1] ECC (Quarries) Ltd.
[2] E & J W Glendenning Ltd.

Carboniferous

The Lower Carboniferous is the major source of limestone in the United Kingdom (Table 30). Extensive outcrops occur in South Wales and the adjacent parts of South-West England, North Wales, Derbyshire, the north of England and Northern Ireland (Figure 9). The material often occurs in thick consistent beds which are easy to quarry, the physical characteristics are those required for good quality aggregate and the chemical purity, in some areas, is outstanding. These qualities, together with outcrop locations conveniently close to most urban centres, except South-East England, have led to the intensive exploitation of Carboniferous Limestone.

Dolomite is present in several areas, although deposits of current commercial significance are largely confined to South Wales, Gloucestershire and Shropshire.

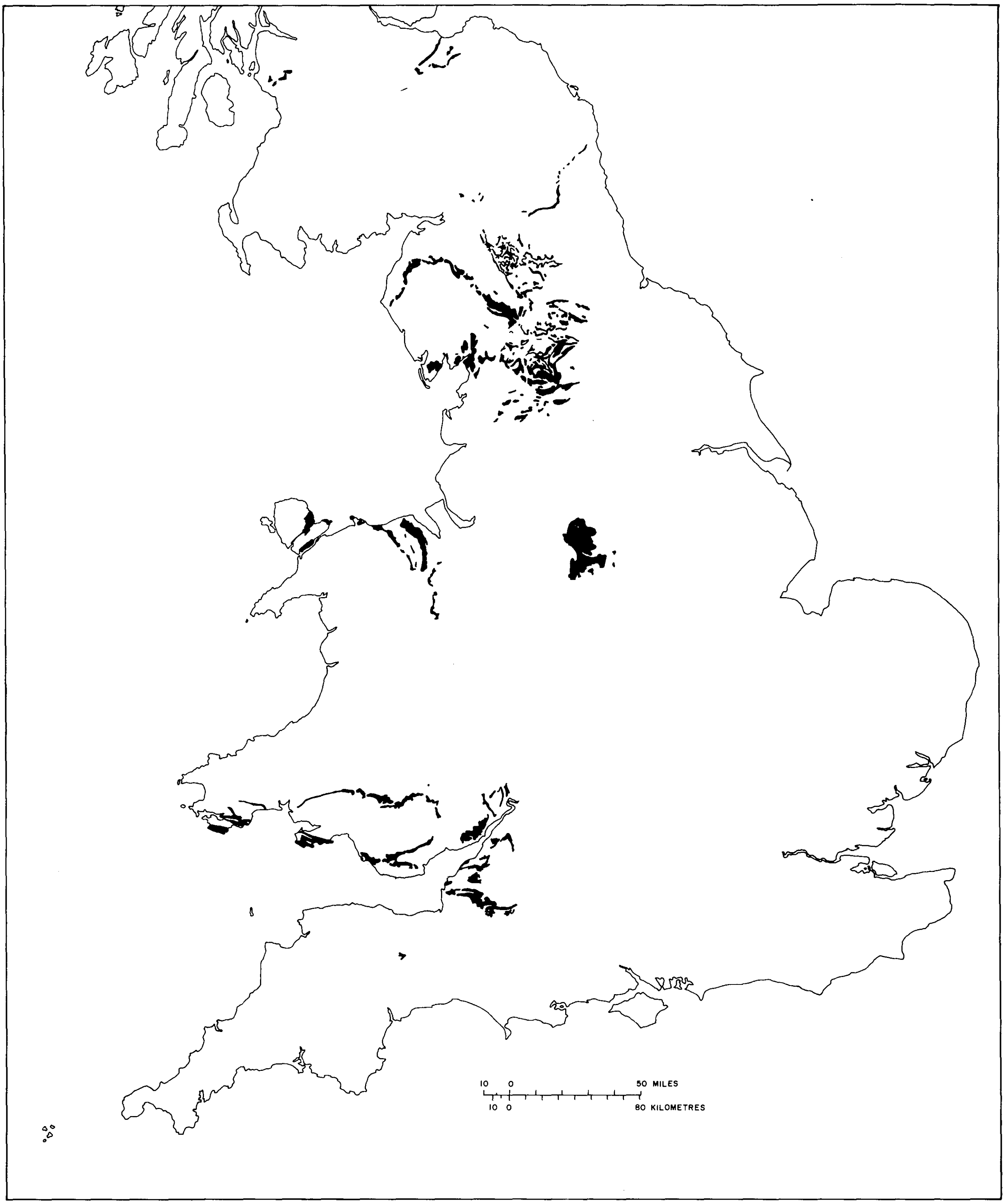


Figure 9 Distribution of limestone resources in the Carboniferous of Great Britain.

South-West England and South Wales

In South-West England and South Wales, Carboniferous limestones reach a maximum thickness of about 1000m in a zone of folding which extends, in an approximately east-west direction, from Pembroke Dock through Gower and the Vale of Glamorgan under the Severn Estuary to the Mendips. To the east,

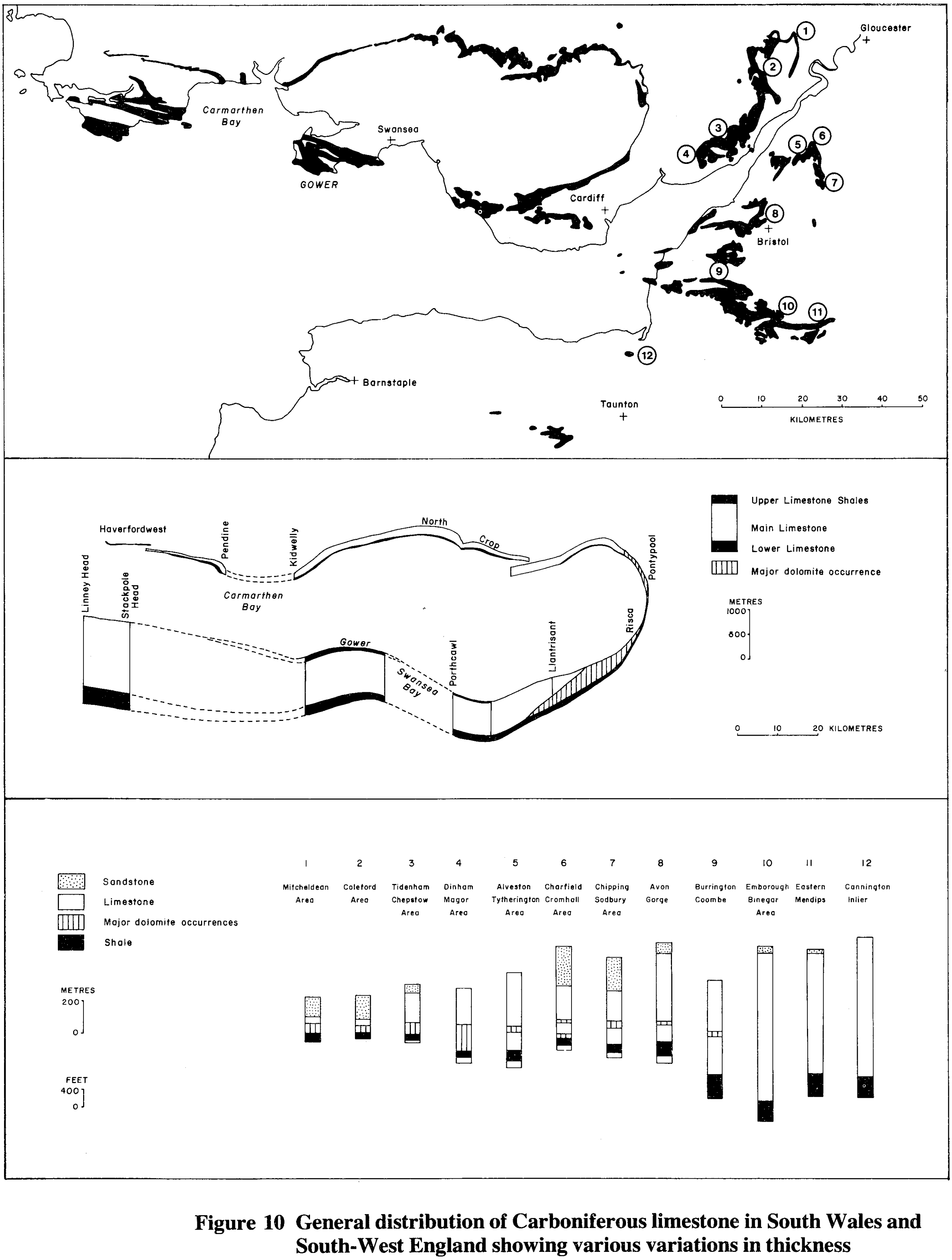


Figure 10 General distribution of Carboniferous limestone in South Wales and South-West England showing various variations in thickness

the limestone outcrop in the main Mendip fold axis extends as far as Frome, Somerset, where it finally becomes buried under a Jurassic cover.

On the north side of the fold belt the limestones become less contorted and thinner. In South Wales they extend beneath the coalfield, cropping out around its flanks to form a series of deposits which are conventionally described in terms of a northern limb where the beds dip southwards up to approximately 20° and a southern limb where there is a corresponding, although usually steeper dip in the opposite direction. Along the "North Crop" the limestones are generally less than 200m thick; on the eastern fringe of the coalfield they are strongly dolomitized and become very thin near Pontypool (Figure 10). In the Forest of Dean and the Wye Valley the limestones also thin to the north and show a significant development of dolomite.

South of the Mendips a thick limestone succession is present in the inlier at Cannington and further south limestones reappear, at Westleigh near Tiverton, in a contorted deposit at the eastern extremity of the Culm formation.

Westwards along the strike of this formation the limestones become thin and impersistent. Southwards they extend under the broad syncline formed by the Culm Measures to reappear in strongly attenuated form in the Meldon Chert Formation which outcrops to the north of Dartmoor.

At present commercial interest in dolomite is confined to deposits in Gwent, Mid-Glamorgan and Gloucestershire. In South Wales, along the "South Crop", the whole limestone formation becomes dolomitised where it approaches the zone of minimum thickness in the Taff's Well–Risca–Pontypool area. In Gloucestershire near Chepstow and in the Forest of Dean, the "Lower Dolomite" crops out extensively and forms an important resource.

Dolomite had also been worked at Clydach near Abergavenny but otherwise the North Crop contains no significant deposits. The Laminosa Dolomite, an important sub-division of the Main Limestone, is said to form important deposits in South Pembrokeshire and Gower, but few details are available, as no systematic work appears to have been carried out on dolomite resources in south-west Wales.

East of the Bristol Channel stratified dolomite occurs in relatively thin, often steeply dipping beds, which offer little opportunity for selective quarrying.

Irregular dolomitisation adjacent to joints and bedding planes is widespread where the limestone is immediately overlain by New Red Sandstone, as in the Vale of Glamorgan near Chepstow and at most of the outcrops in South-West England. The effect of such alteration is usually adverse as it is rarely complete enough to form a workable dolomite deposit and usually introduces sufficient impurities to prevent the limestone being worked other than for aggregates.

In the Bristol area and Somerset several distinct limestones are recognised, the most important in ascending order being Black Rock Limestone, Vallis Limestone, Burrington Oolite, Clifton Down Limestone and Hotwells Limestone. Although significant variations between the limestones can be recognised in places, these for the most part are not sufficiently widespread to enable each bed to be characterised by a unique set of properties relevant to a commercial product. However in Gloucestershire, commercially important changes occur as the Black Rock Limestone is replaced by dolomite and other limestones become locally impure.

Exploitation of limestone in the Meldon Cherts Formation to the north of Dartmoor ceased nearly seventy years ago, although at present there is some reclamation of old waste heaps for use as fill. On the north side of the Culm syncline some steeply dipping, dark coloured, impure basal limestones are worked, mainly for fill, at one quarry at Bampton. To the east these beds are replaced by a much thicker and purer limestone, which, although of limited geographical extent, is exploited from two quarries at Westleigh near Tiverton.

In Somerset the small limestone outcrop at Cannington contains a quarry producing limestone for aggregate, but the main activity is in the Mendips where eleven large quarries between Axbridge and Frome, together, have recently been producing approximately 8 million tonnes a year. The largest producer is Merehead Quarry near Frome, with an annual capacity of 5 million tonnes which dispatches most of its output by rail to terminals in southern England. The nearby Whatley Quarry is also rail-linked and serves similar markets. These quarries, together with three others, are located in a small area in the most easterly part of the Mendips and in some the Carboniferous limestone is worked under a small thickness of Jurassic limestone overburden (Figure 11). Limestones produced from the Mendips quarries usually contain 1–2 per cent silica and 1–2 per cent magnesia, hence although suitable for most aggregate purposes they have relatively little importance for non-construction purposes where high purity is required. However, the Burrington Oolite near Axbridge is recognised as being a stone of unusually high purity for the area and Battscombe Quarry, in this formation, is now the only producer of lime from Carboniferous limestone south of Derbyshire. The lime is used mainly in South Wales for steelmaking and some uncalcined material is used as a flux in sinter. The remainder of the output, together with that of all the other quarries in the area, goes for aggregates with some fines being used in agriculture. Outside the Mendips there are several quarries producing aggregate around Bristol. South of Bristol five large quarries are located in the small area between Brackwell and Winford, together with others at Failand and Weston-in-Gordano. North and east of Bristol several quarries are located in steeply dipping limestones which surround the Bristol Coalfield. These include quarries in an inlier at Wick and at Chipping Sodbury, where a large working has developed along the strike of the steeply dipping Clifton Down Limestone.

Some six km further north, Wickwar Quarry also works the Clifton Down Limestone, but here the rock is more siliceous, enabling stone with a relatively high PSV to be produced which can be used for some road surfacing applications. A nearby quarry at Cromhall is partly in the Black Rock Dolomite, which in this area begins to replace the Black Rock Limestone. The quarry product has a high magnesium content and is significantly stronger than most of the ordinary limestones. Also in this area, Tytherington Quarry, one of the larger producing units in South-West England, works Black Rock Limestone and, being rail linked, can distribute its products over a wide area.

Table 34 Physical and chemical properties of material from quarries located in dolomite in Gloucestershire and Gwent.

	Rogers[1] %	*Livox*[2] %	*Machen*[3] %	*Taff's Well*[4] %
$CaCO_3$	53.2	n.a.	n.a.	56–58
$MgCO_3$	42.6	n.a.	n.a.	39–42
SiO_2	1.85	n.a.	n.a.	1–2
$Fe_2O_3 + Al_2O_3$	2.23	n.a.	n.a.	1.0
L.O.I.	45.8	n.a.	n.a.	
ACV	23	26	25	n.a.
AIV	24	12	14	n.a.
10% fines (KN)	–	300	290	n.a.
AAV	16.6	8.1	7	n.a.
PSV	–	45–50	43	n.a.

Source: [1] Tilcon Ltd.
[2] W. Adams & Co Ltd.
[3] Powell Duffryn Quarries Ltd.
[4] Steetley Minerals Ltd.

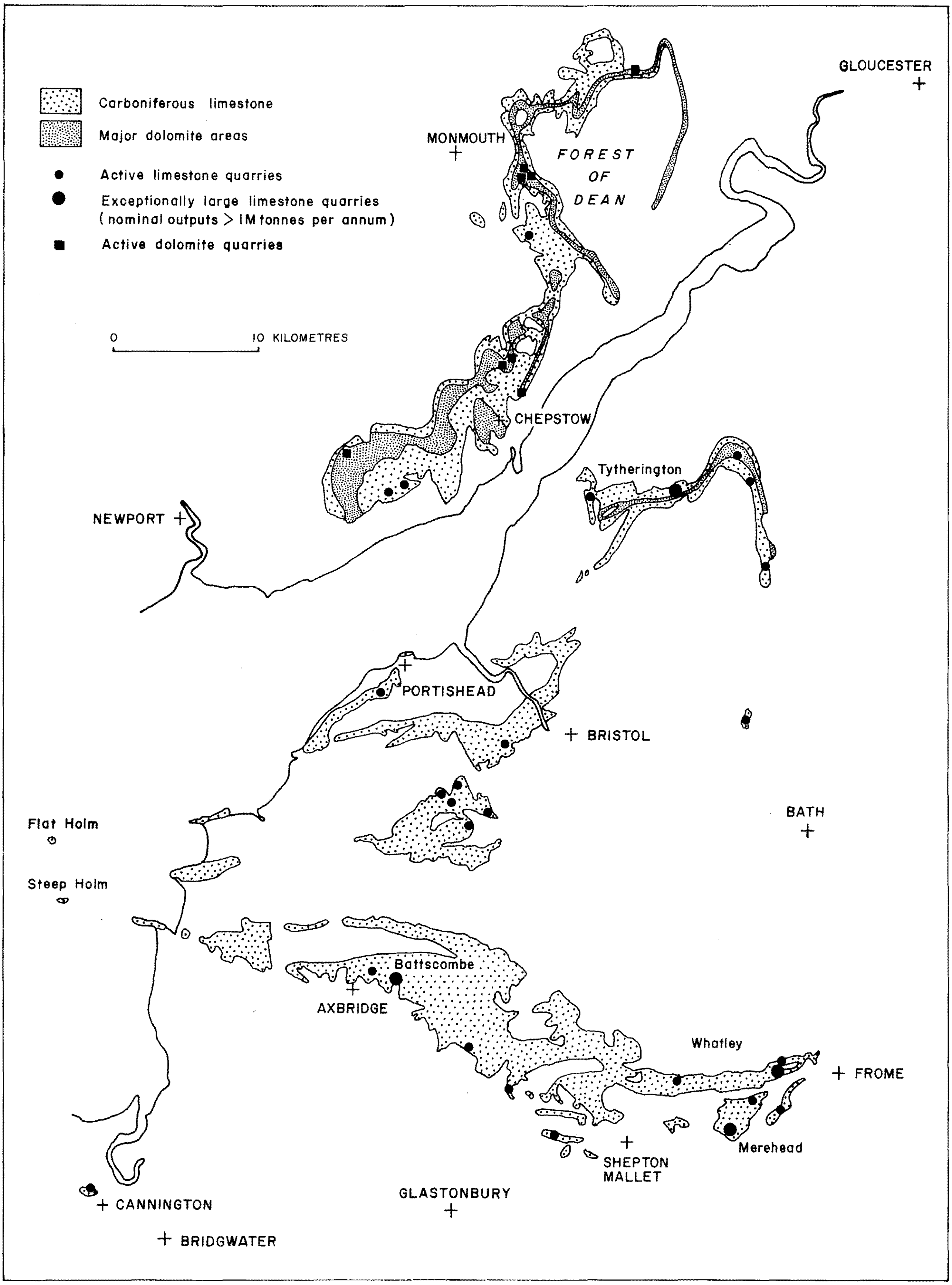


Figure 11 Carboniferous limestone and dolomite in Avon, Gloucestershire, Somerset and eastern Gwent

To the north of the Bristol Channel in the Forest of Dean and adjacent parts of Gwent the choice of quarry sites is affected by the increased thickness of dolomite within the Black Rock Limestone, known in this area as the Lower Dolomite. Several quarries were originally located in the dolomite, which at one time was used for building stone. Some now produce aggregate together with some material used specifically for its magnesium content. In addition there are two quarries near Caerwent in the local equivalent of the Clifton Down Limestone, known as the Drybrook Limestone, and a further quarry at Clearwell in a limestone in the Lower Limestone Shales.

The dolomite quarries in this area produce a stone containing approximately 20% MgO, 1–2% SiO_2 and 1% Fe_2O_3 (Table 34), suitable for use as metallurgical flux. Livox quarry in particular supplies most of its output to steelworks in South Wales. The dolomite is much more resistant than limestone to certain types of abrasion. It gives particularly good values when subjected to the wet attrition test, the major criterion for assessing railway ballast, whereas most Carboniferous limestones are unacceptable for this purpose, even for use on secondary lines. Hence some rail linked dolomite quarries in the Chepstow area are major suppliers of track ballast. Otherwise they tend to supply material for concrete aggregate, roadstone and agricultural purposes.

In the limestone outcrops associated with the South Wales Coalfield, dolomite is worked in some seven quarries located between Risca and Taff's Well (Figure 12). To the west of Taff's Well the proportion of dolomite in the formation decreases rapidly. The most westerly working for dolomite was Hendy Quarry at Llantrisant where some selective quarrying took place over a decade ago. Nearer to Taff's Well, the British Steel Corporation until recently worked Creigiau Quarry for both dolomite and limestone, but difficulties in selective quarrying together with the closure of the main consumer, East Moors Steelworks, Cardiff, have led to its temporary closure.

The major dolomite producing quarries include Taff's Well (Walnut Tree), Cefn Garw, Blaengwynlais, Cwmleyshan, Machen and Risca. Of these Taff's Well is the largest and produces flux for use in sintering, in addition to aggregate. The other quarries are all essentially producers of aggregates and material for agriculture, although Machen Quarry is an important supplier of railway ballast.

Certain dolomites tend to be more resistant to polishing than limestone and some of the quarries in South Wales and Gloucestershire produce material with a PSV of up to 50 which is suitable for certain road surfacing applications.

Between Llantrisant, Cardiff and Porthcawl, the Vale of Glamorgan contains a group of large quarries which together yielded some 3 million tonnes in 1977. Being near to a large population centre in an area which contains little gravel, they constitute the main local source of aggregate. Two exceptions are Ruthin Quarry, which produces material for cement-making at Aberthaw Works and Cornelly Quarry at Stormy Down which produces a flux used in sinter at Port Talbot Steelworks. Many of the limestones in this area include impurities resulting from the proximity of Triassic overburden; to the extent that at Cornelly Quarry a washing plant is used to bring the silica and magnesia content within acceptable limits.

On the north crop of the Carboniferous limestone in South Wales there is much less quarrying than in the period when several iron works operated near the heads of the valleys, in the coalfield, and required nearby sources of flux. At present the output is mainly for aggregate, although Penwylt Quarry, which is rail linked, supplies some flux to Port Talbot.

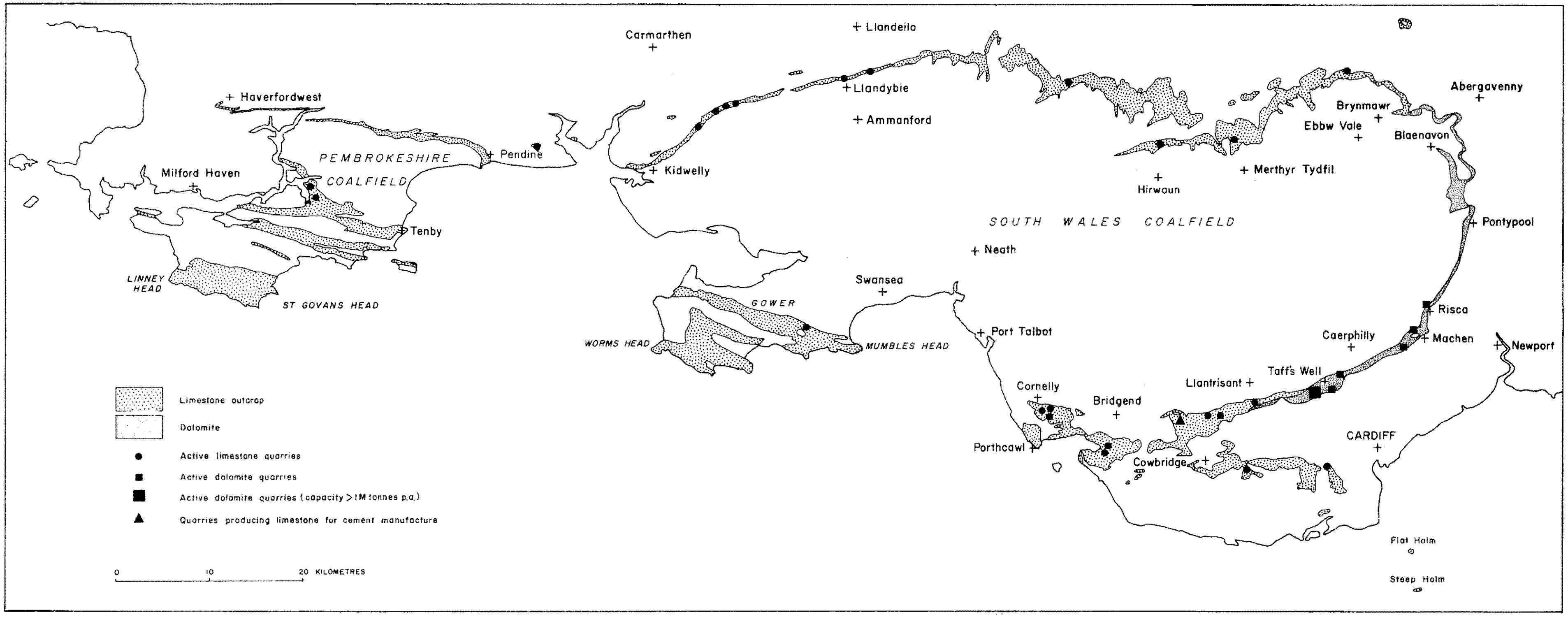


Figure 12 Carboniferous limestone and dolomite surrounding the South Wales Coalfield

Table 35. Chemical properties of limestones from selected quarries in South Wales

	Cornelly[1] %	*Blaenyfan*[2] %	*Cil-yr-ychen*[3] %
CaO	54.7	55.48	55.0 –55.3
MgO	0.4	0.29	0.1 – 0.7
SiO_2	0.51	0.42	0.3 – 0.5
Fe_2O_3	0.12	} 0.28	} 0.14– 0.15
Al_2O_3	0.15		

Source: 1 British Steel Corporation – washed material for use in sinter.
2 Rock Products Ltd, Kidwelly.
3 Lime Firm Ltd, Llandybie.

The narrow, steeply dipping western part of the north crop contains two quarries near Llandybie and a further four quarries to the north east of Kidwelly which now produces only aggregates and agricultural limestone, although analytical data suggests that the chemical purity can be significantly higher than that of limestones from the Vale of Glamorgan (Table 35).

Limestones in Gower and South Pembrokeshire are exploited on only a minor scale although they form thick, extensive deposits. Some fifty years ago there was some coastal movement of agricultural material from Milford Haven to Devon and Cornwall but large coastal quarries did not develop in this area and present exploitation serves only local needs.

North Wales and west Shropshire

Limestone in North Wales occurs in three main areas, in order of economic significance, as follows:

a. The western flank of the North Wales Coalfield, extending from south of Oswestry to the coast at Prestatyn.
b. The west side of the Vale of Clwyd, from south of Ruthin to the coast at Llandulas and ultimately to Great Ormes Head.
c. Anglesey and Menai Straits.

The limestones adjacent to the coalfield are traditionally described in terms of discontinuous Basement Beds succeeded by Lower Grey or Lower Brown Limestone, White Limestone, Upper Grey Limestone and Sandy Limestone. These divisions are locally arbitrary and there is little evidence that they have any economic significance except for the Sandy Limestone, a variable formation which in places contains sandy limestones together with beds of shale and sandstone. At Halkyn Mountain the limestones reach a maximum thickness of approximately 750m, of which the top 150m represents the Sandy Limestone, while towards the coast the thickness decreases slightly and argillaceous black limestone develops at the top of the succession. To the south there is a considerable decrease in thickness, although the attenuation is not uniform (Figure 13).

Limestones on the west of the Vale of Clwyd are less well known than those to the east but the sequence is comparable and the Sandy Limestone is present over much of the area, although to the west of Abergele the usual divisions become increasingly difficult to recognise.

In Anglesey the limestone sequence is thinner and because deposition occurred near the margin of the area of sedimentation, bands of sandstone or shale are present.

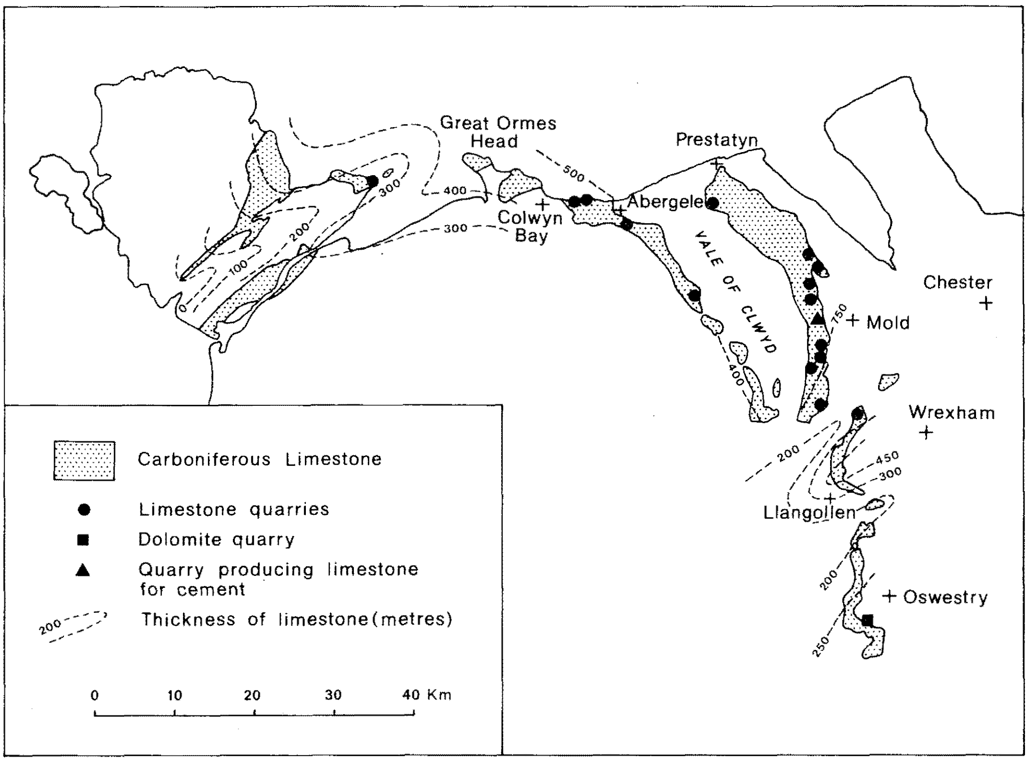


Figure 13 Carboniferous limestone in North Wales and Shropshire

Dolomite occurs infrequently in the area. The most important deposit is located near Llynclys, south of Oswestry, where irregular dolomitisation has developed within the White Limestone. Dolomitised beds also occur at Penmon in north-east Anglesey, on nearby Puffin Island, and in the Lower Brown Limestone near Llandudno.

Quarrying in North Wales is largely aimed at production of aggregates and exploitation is concentrated in outcrops closest to markets in Merseyside and Cheshire, which are mainly served by road transport. The limestones are often of relatively high purity although some quarries high in the succession work into the Sandy Limestone and produce a more siliceous and abrasive material.

Among the non-aggregate producers, Cefn Mawr Quarry near Mold is entirely devoted to the production of limestone for cement making. The material is transported by road to the Padeswood Works of Tunnel Cement Ltd, where it is mixed with shale reclaimed from nearby colliery spoil heaps. Several quarries located in high grade limestone produce material for specialised purposes, such as coal mine dust, flux, glass making, fillers and animal feed stuffs, as a by-product of aggregate production. Abergele Quarry produces lime for use in water treatment, while nearby at Llanddulas two large coastal quarries produce high quality material, some of which is exported for use in steelmaking and calcium carbide manufacture (Table 36).

In Anglesey, quarrying is restricted to two small inland units which produce hardcore and some building stone, together with a larger coastal quarry at Penmon, which formerly had a jetty, but now serves only local markets. In addition at Moelfre the local limestone, known as Moelfre Marble, is worked on a small scale for building, monumental and polished stone. On the mainland building stone is produced at a small quarry at Llanddulas.

Table 36 Properties of limestone from selected quarries in North Wales

	Abergele[1] %	*Trimm Rock*[1] %	*Pant*[2] %	*Halkyn*[3] %
$CaCO_3$	98.90	98.90	97.34	96.98
$MgCO_3$	0.43	0.49	0.48	0.8
SiO_2	0.19	0.48	1.07	0.6–1.0
Fe_2O_3	0.03	–	} 0.01	0.06
Al_2O_3	–	0.12		0.12
ACV	27	23	25	24
AIV	28	22	19	24
AAV	–	–	15	14
10% fines value (kN)	120	190	160	186
PSV	–	–	42	40

Sources: [1] Tilcon Ltd.
[2] Wimpey Ltd.
[3] R.M.C. Ltd.

Dolomite is worked only at Llynclys Quarry near Porthywaen and the product is used entirely for agriculture. Dolomitic limestone for agricultural purposes is also produced in a small working at Llangwstenin near Llandudno.

North Wales possesses the only calcspar mine outside Derbyshire. The workings are in veins of calcite in limestone near Hendre. The product is used as pebble dash and as a filler in road marking paint.

Derbyshire and Staffordshire

Carboniferous limestone in the Peak District of Derbyshire and adjacent parts of Staffordshire forms an extensive dome-like structure with an outcrop extending from near Castleton in the north to Wirksworth in the south-east. There are also two small inliers at Crich and Ashover (Figure 14).

The limestones fall into two distinct groups depending on the environment in which they were deposited. Over most of Derbyshire the limestones were deposited on a fairly stable rigid area known as a "shelf", while in the south western part of the outcrop, mainly in Staffordshire, deposition took place in a "basin" area with deeper water and more rapid subsidence. In the extreme south-west, shelf deposition is also evident in a small area near Cauldon.

Limestones on the shelf are characterised by having low angles of dip, considerable consistency and relative absence of shale. In the basin area the succession contains more shale and argillaceous limestone and tends to have been subjected to more intense folding. The boundary between the two areas is frequently marked by the presence of a fringing reef in the shelf limestones. The basin area is of little importance in quarrying largely because of the close proximity of better quality limestone in the shelf area.

The limestone succession in the Derbyshire shelf area is as follows:

Eyam Limestones
Monsal Dale Limestones
Bee Low Limestones
Woo Dale Limestones

The Woo Dale Limestones underlie the area in depth but outcrop only in anticlines in the northern and western parts of the district where they consist of

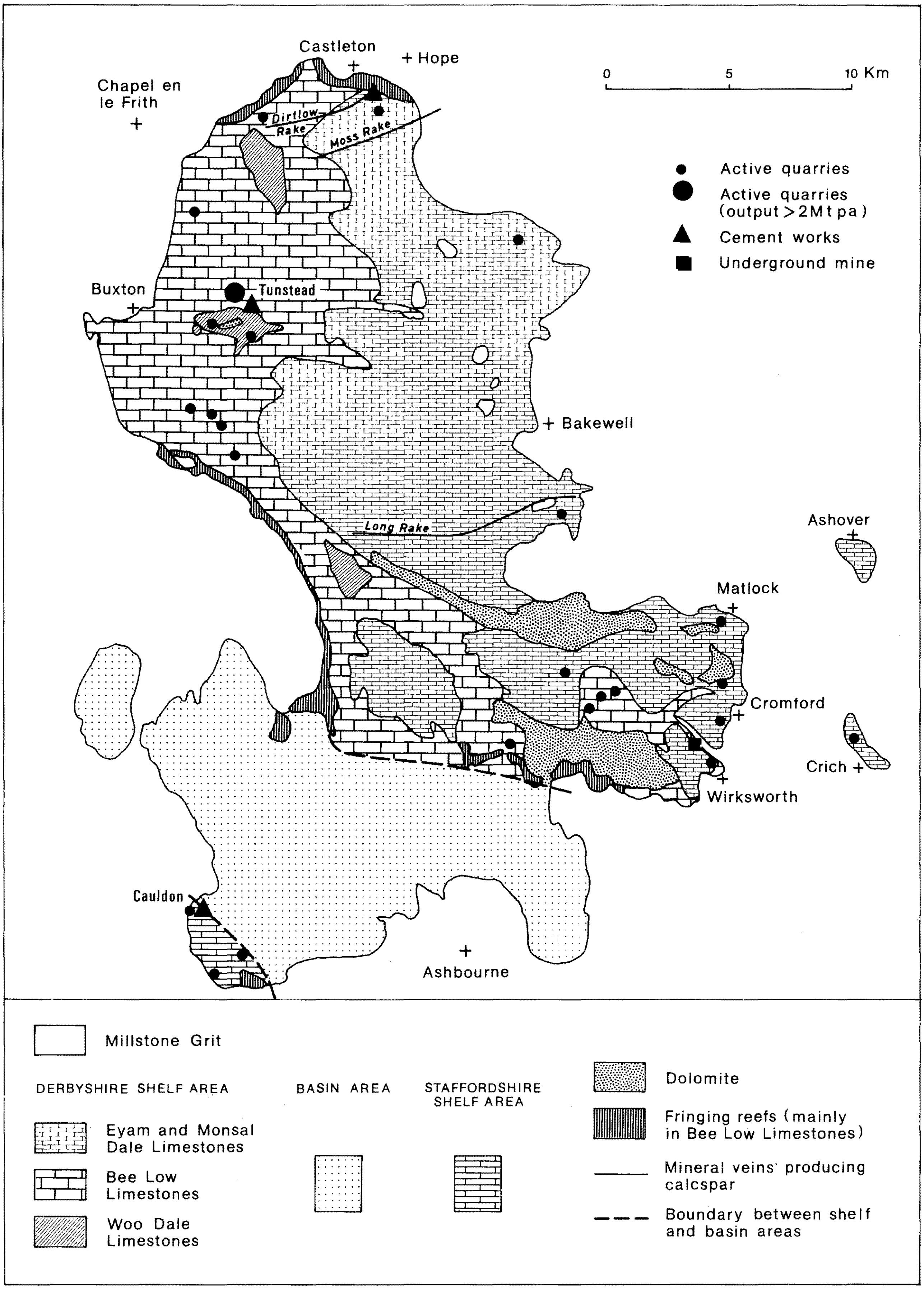


Figure 14 Carboniferous limestone in Derbyshire and Staffordshire

high purity limestone. The lower part of these beds contains dolomite which outcrops only in the centre of an anticline near Buxton.

The Bee Low Limestones are the most quarried formation in Derbyshire and without doubt one of the most important mineral resources in the country. These limestones are some 200m thick in the Buxton area thinning southwards to about 75m near Wirksworth. They outcrop over a wide belt along the western and southwestern margin of the shelf area (Figure 14). Usually of exceptional purity and consistency, the Bee Low Limestones consist of massive beds which are divided by some 20 widely spaced, 0.5m thick clay beds known locally as clay "wayboards". These are removed during processing, either by washing or by systematic dry screening to remove fines.

The Monsal Dale Limestones have an extensive outcrop in the shelf area but in contrast to the underlying beds tend to be variable in composition and frequently contain impure thinly-bedded limestone and chert in addition to more massive material. Although high quality limestone is present in places in the Monsal Dale beds it is not exploited for high grade end uses, probably because of difficulties in maintaining a consistent product.

The Eyam limestones which succeed the Monsal Dale Limestones are relatively thin and consist mainly of dark, impure limestones together with shale and chert.

Other than the small outcrop in the Woo Dale Limestones near Buxton, dolomite occurs only in the south-east part of the area where it is thought to have been formed by the action of solutions derived from a former cover of Keuper Marl. Dolomitisation affects a large area in the Bee Low Limestones to the west of Wirksworth and part of the Monsal Dale Limestones in the Matlock area.

IGS is currently making a detailed assessment of the location and properties of Carboniferous limestones in Derbyshire. Reports and maps on a scale of 1:25000 have been published and others in preparation will cover the entire limestone outcrop.

Derbyshire is the main producing county for high purity, industrial limestone in the United Kingdom and the relevant quarries are located either in the Bee Low Limestones or to a lesser extent in the Woo Dale Limestones. Quarries in the Monsal Dale and Eyam limestones and in Staffordshire concentrate only on the production of aggregate and cement.

The major producing unit is Tunstead Quarry owned by Imperial Chemical Industries which has a nominal capacity of 5 million tonnes a year. Situated to the east of Buxton in Great Rocks Dale it exploits Bee Low Limestones with some limited workings in the Woo Dale Limestones. The traditional and most important single element of production is 1.5 million tonnes a year of limestone which is moved by rail to Winsford, Cheshire, for use in the ammonia-soda process. A further 1–2 million tonnes a year is calcined on site for sale as lime or hydrated lime and most of the remainder is used for aggregate, together with some carbonate sold for other industrial uses. The processing plant incorporates a washing stage to remove clay impurities and a small cement kiln is operated at the quarry to utilise the residues.

Other quarries in the Buxton area which produce material of high chemical purity included Eldon Hill Quarry, near Castleton; Dove Holes Quarry at Dove Holes; and Hillhead, Hindlow, Dowlow and Brierlow quarries on adjacent sites to the south of Buxton. Also in the Buxton area, Topley Pike and Ashwood Dale quarries work the Woo Dale Limestones (Table 37) and Topley Pike has some workings in Bee Low Limestones.

In the southern part of the outcrop, Bee Low Limestones are worked at three quarries, Grange Mill, Brassington Moor and Prospect, on adjacent sites at Grangemill. There is a further large quarry some four kilometres to the south-west at Ballidon.

In the Wirksworth area the Bee Low Limestones are relatively thin and have a restricted outcrop. They are worked together with the overlying Monsal Dale Limestones at Middlepeak Quarry and selectively extracted at the nearby Middleton Mine; one of the very few limestone mines in the United Kingdom. It originated as an underground extension of a surface quarry which encountered difficulties in the removal of overlying Monsal Dale Limestones.

Table 37 Chemical composition of limestone based products from quarries in Derbyshire.

	1 %	*2* %		*3* %
CaO	96.39	96.24	$CaCO_3$	98.6
$CaCO_3$	1.85	2.14	$MgCO_3$	0.8
$CaSO_4$	0.38	0.04	Al_2O_3	0.01
MgO	0.40	0.79	Fe_2O_3	0.05
Fe_2O_3	0.12	0.10	Mn_2O_3	0.02
Al_2O_3	0.22	0.60	CuO	0.005
SiO_2	0.71	0.53	SiO_2	0.5

Sources: 1 150–38mm lump lime; Tunstead Quarry, ICI Ltd.
2 25–1.5mm lump lime; Tunstead Quarry, ICI Ltd.
3 Limestone powder; Dowlow Quarry, Steetley Minerals Ltd.

The other quarries in Derbyshire work the Monsal Dale or Eyam limestones and they, together with the Staffordshire quarries near Cauldon Low, are essentially aggregate producers, except for two large cement works located at Hope and Cauldon, both of which work relatively impure limestones for admixture with local shales.

Derbyshire is also the major producer of vein calcite which is said to occur in commercial quantities only in the Dirtlow Rake, Moss Rake and Long Rake mineral veins. At present it is produced as a byproduct of fluorite and barite workings in the Dirtlow Rake and Moss Rake. However the major working, the mine of the Long Rake Spar Co., located near Youlgreave, recovers calcspar as its main product from underground workings up to 150m deep.

At present, dolomite is worked in Derbyshire on only a small scale for aggregates in Ball Eye Quarry near Cromford where the workings extend into dolomitized parts of the Monsal Dale Limestones. However, from 1963 to 1966 dolomitized Bee Low Limestones, from a quarry near Hopton, were used in the production of magnesium metal from calcined dolomite using ferro-silicon (Pidgeon Process), but the process was commercially unsuccessful in the United Kingdom.

Derbyshire limestone, because of its consistency, purity and proximity to major industrial centres, has been of importance since the early days of the industrial revolution. Development was facilitated by an early railway which followed the outcrop of the Bee Low Limestones between Wirksworth and Buxton to give good communication with industrial markets in north-west England and the Midlands. Subsequently, several other railways were constructed and rail haulage is still used extensively for the transport of limestone from the area. Hope cement works, Middlepeak Quarry, Wirksworth, and most of the quarries in the Buxton area, including Tunstead, have rail connections.

Central England

Several isolated outcrops of Carboniferous limestone occur in the English Midlands and some adjacent areas. In addition limestone underlies younger rocks throughout much of the area although there was an E–W barrier, extending roughly from central Wales through Birmingham to the Wash, over which limestone was not deposited.

The only area currently being exploited is near Ashby-de-la-Zouch, on the north-east margin of the Leicestershire Coalfield, where there are some small isolated inliers of limestone, two of which, Breedon Cloud and Breedon Hill, contain active quarries. Workings are intensive and much of the aggregate produced is a dolomite.

Elsewhere in the East Midlands, limestones occur beneath the Leicestershire Coalfield and the northern parts of the South Staffordshire and Warwickshire Coalfields. They also extend under the Derbyshire and Nottinghamshire Coalfield. In the West Midlands there are a few small inliers of limestone near Lilleshall and Little Wenlock, Shropshire and at Titterstone Hill near Kidderminster. On the south side of the midland barrier Carboniferous limestone, approximately 100m thick, lies at a depth of 100m under Cambridge. Limestone is also present at depth between Kettering and Northampton.

North Yorkshire, Cumbria, Lancashire and the Isle of Man

Carboniferous limestones in Northern England, like those in Derbyshire, fall into two groups "basin" and "shelf", depending on their depositional environment.

In southern Ribblesdale and near Skipton Lower Carboniferous rocks comprise a "basin" type sequence consisting essentially of shales, bedded limestones and irregular reef limestones. The bedded limestones, known as Chatburn or Haw Bank Limestone, are folded and relatively impure. They are succeeded by a thick series of shales containing some thin limestone bands together with lenticular limestone masses known as knoll-reefs. There is a concentration of knoll-reefs near the Mid-Craven Fault, near Clitheroe. The reef limestones are often of high purity and although many occur in relatively small masses some are large enough to support a modern quarrying operation.

North of the Mid-Craven Fault there is an abrupt change in the sequence as the strata of the "shelf" area replaces that of the "basin". The essentially stable area of sedimentation characteristic of the shelf extends throughout the Yorkshire Dales and parts of Cumbria. The sequence consists of a lower series of thick, pale coloured limestone, popularly known as the Great Scar Limestone in North Yorkshire, succeeded by an alternating sequence of limestone, sandstone and shale (formerly known as the Yoredale Series). The major limestones within this group in North Yorkshire include the Hardraw Scar, Simonstone, Middle, Five Yards, Undersett and Main. The Main Limestone, known further north as the Great Limestone, at the base of the Millstone Grit Series is at present the only limestone other than the Great Scar Limestone which is being worked in the area. In Cumbria, the same divisions can be recognised although local names are sometimes used. However the Great Scar Limestone splits into several units in the area between Tebay and Penrith, and the whole sequence becomes thinner in the Cockermouth/Whitehaven area (Figures 15 and 16).

In the Isle of Man there are outcrops of Carboniferous limestone in the northern and southern parts of the island, which are comparable in thickness to the deposits in West Cumbria.

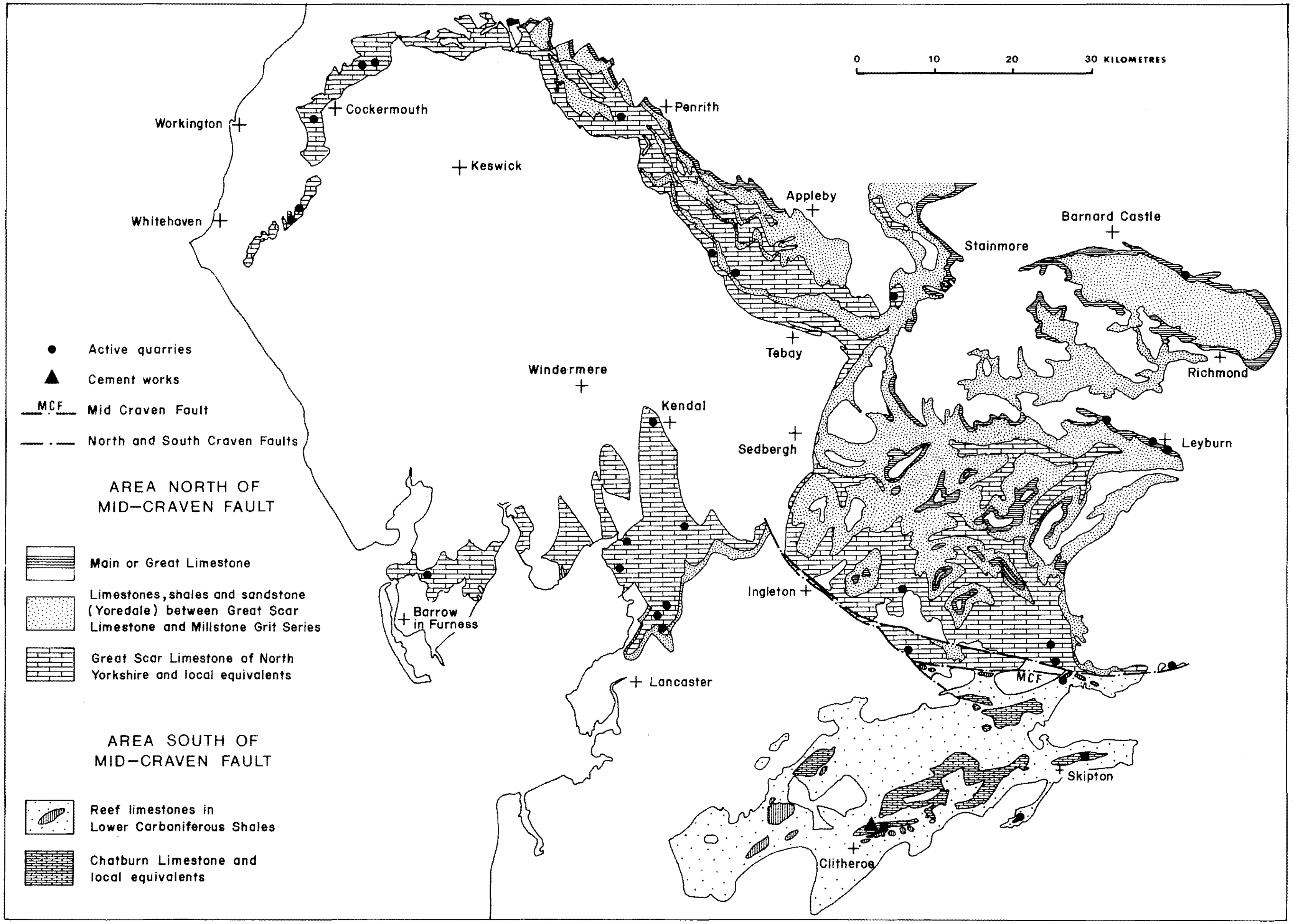


Figure 15 Carboniferous limestone in N. Yorkshire, Cumbria & Lancashire

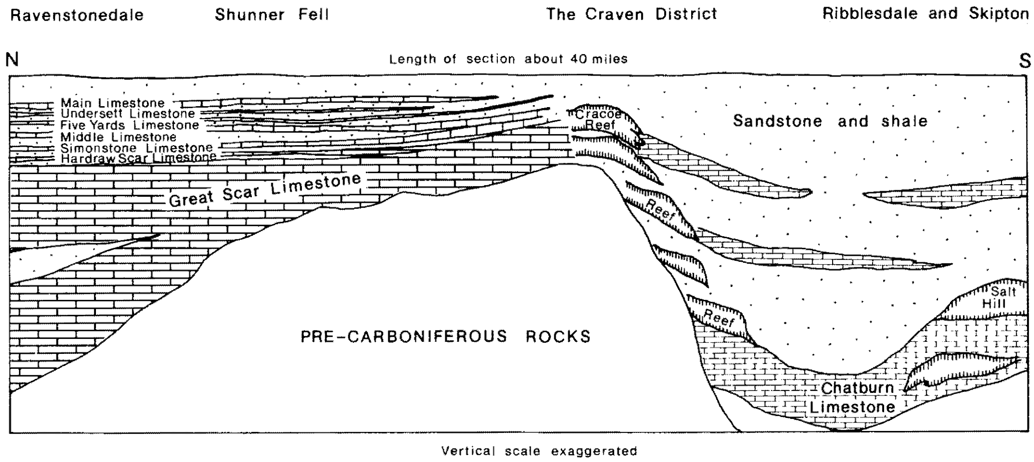


Figure 16 Diagrammatic N–S cross section showing "basin" and "shelf" areas of sedimentation in northern England

In the Chatburn Limestone outcrop near Clitheroe, Lancashire, dark coloured carbonaceous limestone, containing approximately 95% calcium carbonate, and interbedded shales, containing 30% calcium carbonate, form a natural cement mixture which is exploited by Ribblesdale Cement Ltd. The cement company also produces limestone aggregates from the same quarry and there is another large aggregate quarry on an adjacent site. Although not under a single ownership, the complex of quarries at Clitheroe constitutes one of the larger limestone producing operations.

At Skipton, the Haw Bank Limestone, the local equivalent of the Chatburn Limestone, is exploited at Skipton Rock Quarry. The beds of limestone are sharply folded and the workings are confined to the relatively narrow core of an anticline. There is another working in "basin" limestone at Lothersdale south west of Skipton.

Although some limestone knolls at Clitheroe were worked until recently, extraction of reef limestone is now confined to one large quarry in the Swinden Knoll, on the south side of the Craven fault near Grassington. The stone is of high quality and part of the output is used for producing lime. The quarry is rail linked and supplies some aggregate to terminals at Hull and Leeds.

To the north of the Mid-Craven Fault in North Yorkshire, and around the fringes of the Lake District, the Great Scar Limestone offers many sites suitable for quarrying. However, a slight dip makes the limestone less accessible to the north where it is increasingly covered by higher sediments. Hence the Great Scar Limestone in Wensleydale outcrops only in the bottom of the dale where it is often covered by thick drift deposits to such an extent that quarrying is confined to the Main Limestone, both in this area and in the remainder of northern North Yorkshire.

Exploitation of the Great Scar Limestone in the Craven area is centred on quarries at Horton, Giggleswick, Threshfield, Kilnsey and Pateley Bridge. Threshfield Quarry lies in a zone of dolomitisation associated with the adjacent North Craven Fault. Although worked for aggregates at present, it is unique in the Carboniferous of Northern England in that at one time it produced dolomite for agricultural purposes. In contrast, the nearby quarry at Kilnsey, together with those at Horton and Giggleswick are located in thick, high purity limestone.

Horton Quarry, formerly owned by Imperial Chemical Industries and now owned by Tarmac Roadstone, is the largest in the group. It is rail linked and produces both lime and limestone for flux, chemicals and other purposes (Table 38).

In north-west Cumbria, limestone is worked at two adjacent quarries at Rowrah, near Whitehaven towards the southern end of the outcrop. The limestone is relatively thin and stained a deep red colour by local hematite; however, the material is free from dolomite and until 1978 was used for flux in the steelworks at Workington although it is now used only for aggregate. Further north, in the Cockermouth area, where the limestone becomes thicker and relatively free from iron staining, there are three quarries which are essentially aggregate producers although some material has been sold for flux. At Caldbeck there is a relatively small aggregate working in the Great Limestone.

Table 38 Properties of material from selected quarries in northern England

	Horton[1] %	*Horton*[2] %		*Swinden*[3] %	*Lothersdale*[3] %
CaO	91.29	95.49	$CaCO_3$	97.82	91.16
$CaCO_3$	7.31	2.96	$MgCO_3$	0.84	1.26
$CaSO_4$	0.80	0.97	SiO_2	1.21	6.86
MgO	0.34	0.31	Fe_2O_3	.01	0.32
Fe_2O_3	0.08	0.08	Al_2O_3	—	0.25
Al_2O_3	0.13	0.13			
SiO_2	0.13	0.16			
			AIV	27	15
			AAV	15	10
			ACV	27	22

Sources: 1. 150–50mm lump lime; ICI Ltd.
2. Fine lime (< 7 mm); ICI Ltd.
3. Tilcon Ltd.

In the area between Penrith and Kirkby Stephen along the north-eastern flank of the Lake District the Great Scar Limestone is thick and extensive offering several attractive sites for quarrying. Although it is stained red in the quarries at Blencowe near Penrith, Shap Fell, and Kirkby Stephen, in most areas it is relatively free from dolomitisation.

Until recently several quarries in this area had lime making facilities but now calcination is carried out only at Hartley Quarry, Kirkby Stephen and at Hardendale Quarry, Shap, owned by the British Steel Corporation, where a relatively pure limestone deposit forms the basis of an important industry. The quarry was originally opened by Colvilles Ltd. to provide flux for their steelworks in Scotland. More recently it has expanded and now includes three kilns which supply lime for steelmaking to plants in Scotland and Teeside. In this area there is also some production of building and ornamental stone from a small quarry near Orton.

The area of limestone between Lancaster and Kendal is of great importance in terms of production. It accommodates seven quarries of which Holme Park Quarry, Holme, is the largest single unit, although three quarries on adjacent sites at Carnforth constitute an important complex. In general, quarries in this area tend to concentrate on aggregate production and those with good motorway access distribute material as far south as Manchester and Liverpool. There appears to be little difference in quality between the material in this area and that occurring in the Yorkshire Dales. The limestone is of considerable thickness, white in colour, and generally free from magnesium or other impurities.

Around the western fringe of Morecambe Bay there is now little limestone quarrying. At one time a large quarry operated near Barrow to supply the local steelworks, but both are now closed, leaving only one producing quarry in Furness which largely satisfies local aggregate needs. The Isle of Man is self sufficient in limestone, which is quarried near Castletown for agriculture and aggregate purposes.

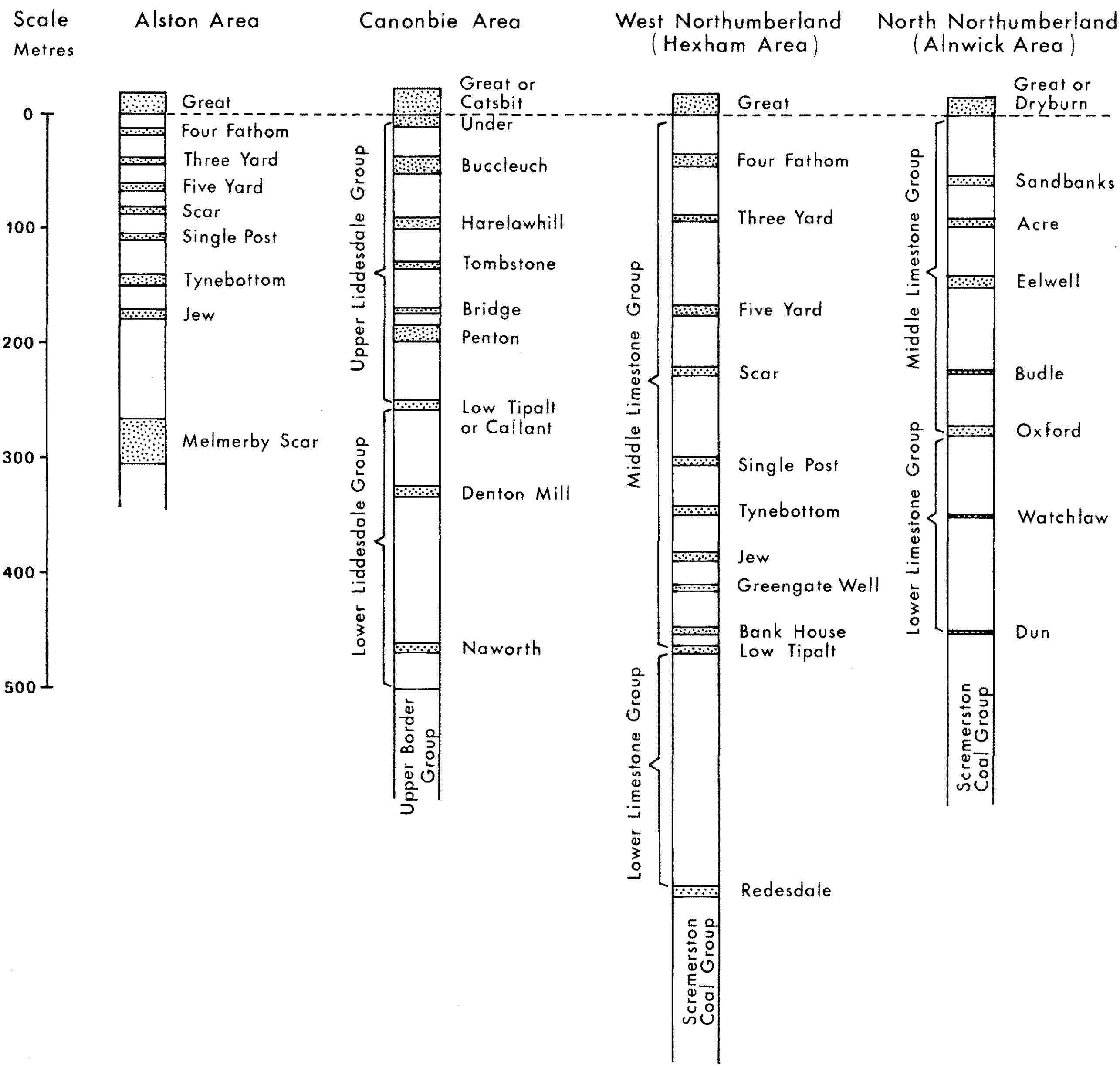


Figure 17 Vertical sections showing the major limestones in north-east England and adjacent parts of Scotland

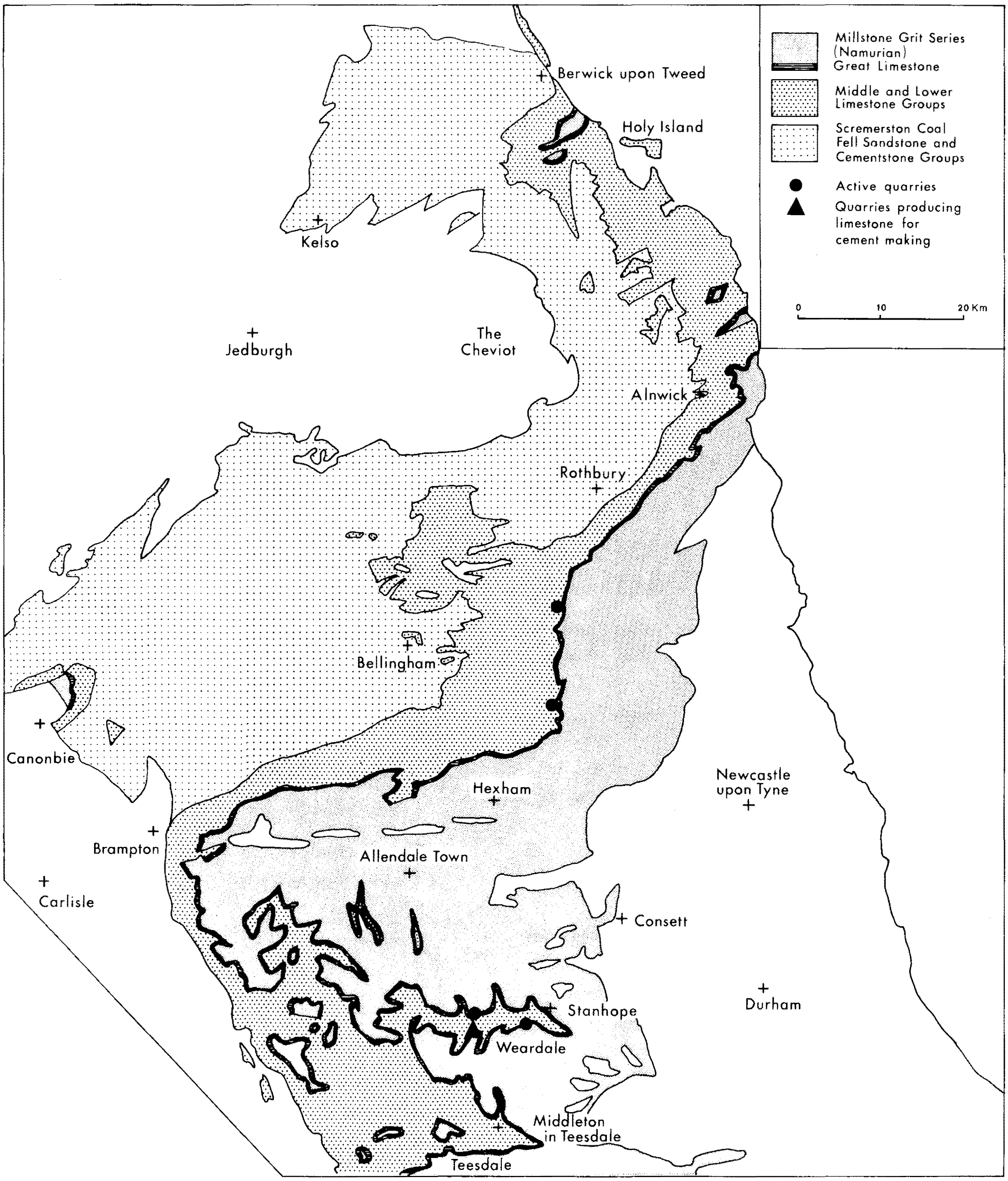


Figure 18 Limestone and limestone bearing formations in the Carboniferous of north-east England and southern Scotland.

Northumberland, Durham and Scottish Borders

North of Stainmore, limestones in the Lower Carboniferous form a lateral continuation of those in North Yorkshire except that the Great Scar Limestone, represented in this area by the Melmerby Scar Limestone, dies away and the individual limestones within the overlying beds become thinner and more widely separated. However, the Great Limestone, the equivalent of the Main Limestone further south, is present throughout the area and is the only limestone currently exploited. The relationships between the more important limestones, local names and thicknesses throughout the area are shown in Figures 17 and 18.

The Lower Carboniferous in the northern part of the area consists of a lower Cementstone Group which includes some thin, argillaceous, dolomitic limestones or "cementstones" interbedded with shales and sandstones. This is succeeded by the Fell Sandstone Group, which contains no limestones and the Scremerston Coal Group which contains only a few thin limestones. Between the Scremerston Coal Group and the Great Limestone, the Lower Limestone and Middle Limestone Groups include several limestones which may exceptionally reach a maximum thickness of 20m. The Great Limestone itself, which forms the base of the Millstone Grit, is the uppermost limestone of any significance although there are a few thin limestones at higher levels in the Millstone Grit.

In the north-west of the area near the Canonbie Coalfield, there are restricted outcrops of the Millstone Grit and Middle and Lower Limestone groups (locally known as Upper Liddesdale and Lower Liddesdale groups respectively). Although the limestones are broadly similar to those occurring in Northumberland, and the Great Limestone (known in Scotland as the Catsbit Limestone) is present, workings were mainly in the Harelawhill Limestone which was worked by underground methods until about twenty years ago.

The Great Limestone is worked in Northumberland on a relatively large scale at Mootlaw Quarry and at Greenleighton Quarry. At Mootlaw the limestone is approximately 15m thick and relatively flat lying. It contains some thin bands of shale which are removed by screening and washing the product prior to sale for use mainly as concrete aggregate and coated roadstone.

In Durham the Great Limestone is exploited only in Weardale where there are at present two active workings near Eastgate. The larger of these supplies limestone and associated shale to the Weardale Cement Works, while the smaller quarry produces aggregate. There are proposals for opening a new quarry in the Eastgate area.

Midland Valley of Scotland

The Dinantian (Carboniferous Limestone Series) in the Midland Valley of Scotland comprises the Calciferous Sandstone Measures and the overlying Lower Limestone Group. In the east, where they are most thickly developed, the Calciferous Sandstone Measures are divided into three lithological formations, the Cementstone Group at the base and the Lower and Upper Oil-Shale groups. The two lower groups contain limestone only in very thin bands, many of which are argillaceous and/or dolomitic. The Burdiehouse Limestone, quarried and mined in Midlothian, is taken as the base of the Upper Oil-Shale Group. Similar freshwater limestones of medium to high purity have been worked in West Lothian and Fife, but their postulated correlation with the Burdiehouse is not substantiated. They attain a thickness of about 7m in Fife but locally in West Lothian exceed 14m.

In the west, much of the Calciferous Sandstone Measures is composed of volcanic rocks, with local development of Cementstone Group lithologies.

The Lower Limestone Group contains most of the workable limestones in Scotland, notably the basal band, known as the Hurlet Limestone in the Glasgow-Paisley area and elsewhere as Broadstone, Main, Charlestown Station, Gilmerton, or Upper Longcraig, the name changing as its outcrop is followed from Strathclyde to the Central, Fife and Lothian regions. Another much worked band is the Blackhall of Glasgow and Paisley, elsewhere known as the Dockra, Charlestown Main, Petershill, North Greens, or Middle Skateraw.

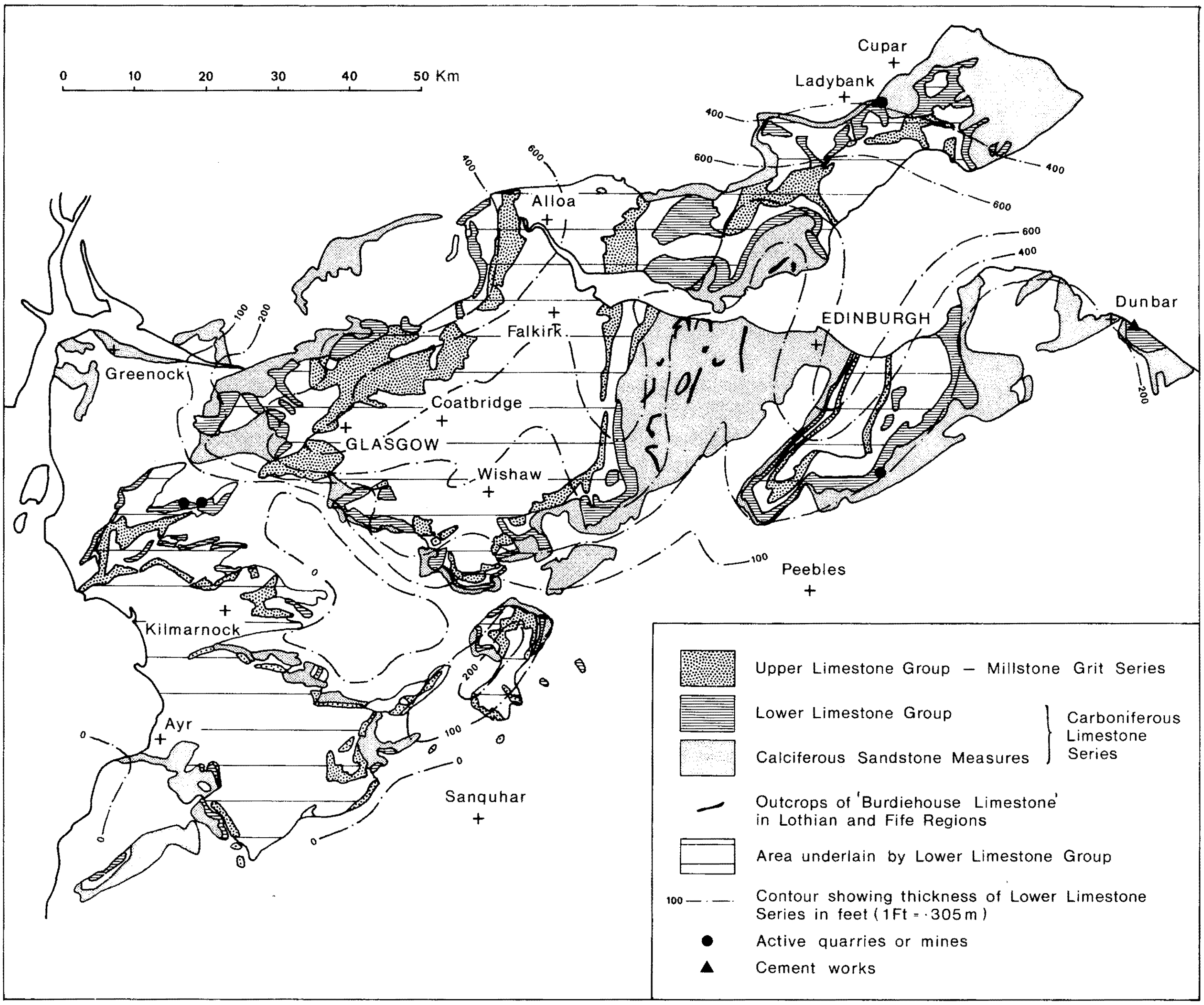


Figure 19 Carbonferous limestone-bearing formations in the Midland Valley of Scotland

Some of the Hosie limestones of Paisley have also been worked, notably the McDonald in the Douglas area of Strathclyde and the Bilston Burn in Midlothian.

The Namurian (Millstone Grit Series) of the Midland Valley includes the Upper Limestone Group. The Index and Calmy limestones, from this formation, have been worked at many localities in Strathclyde, the Castlecary Limestone mainly around Linlithgow, and the Lyoncross and Orchard limestones just south-west of Glasgow.

The limestones in the Midland Valley very rarely exceed 10m in thickness and are more frequently 3m thick or less. They have been extensively worked in the past, often to provide flux for the local iron and steel industry. The pressure on the limited resource was so intense that traditional quarrying methods were frequently replaced by underground workings.

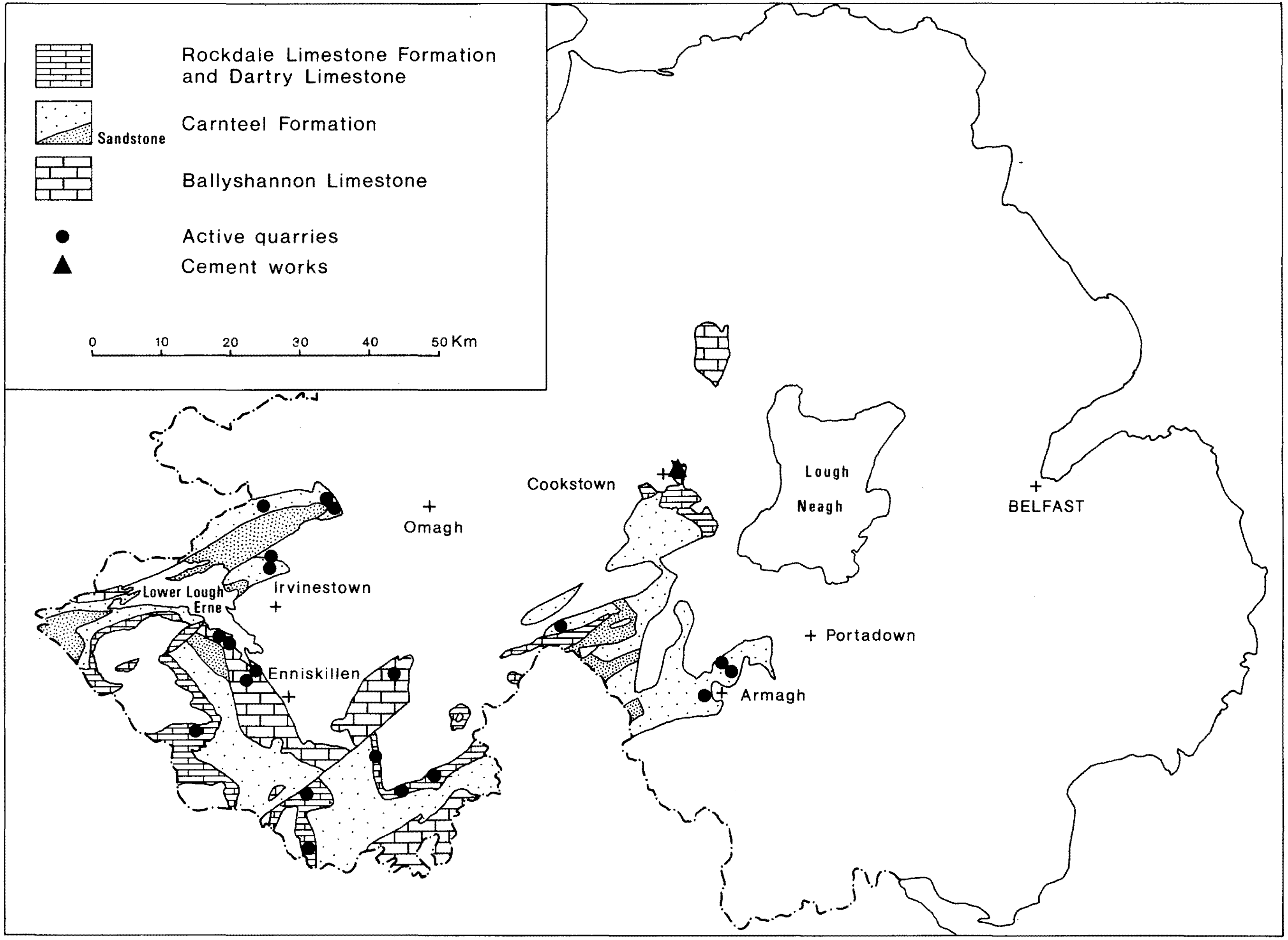


Figure 20 Distribution of Carboniferous limestone in Northern Ireland

At present there are only five active limestone workings in the Carboniferous of Scotland. Two of these are located near Beith to the south-west of Glasgow, in the Dockra Limestone. In Fife there is an underground mine at Cults in the Charlestown Main Limestone and in Lothian the same seam, locally called North Greens Limestone, is quarried at Middleton near Gorebridge, where it yields a product containing 90% $CaCO_3$, 2.3% MgO, 6.3% SiO_2 and 1.4% Fe_2O_3. Until 1979 the North Greens Limestone was also worked underground at Cousland, Lothian, to produce a ground product containing 70–80% calcium carbonate which was used in agriculture. Most quarries in Scotland produce ground limestone for use as filler in asphalt or in agriculture, rather than material suitable for aggregates.

The only cement works in Scotland is located at Dunbar and is based on local limestone extracted from the Upper Longcraig Limestone and the Middle Skateraw Limestone which occurs at a slightly higher level. Shales from the same quarry provide the necessary argillaceous matter. As a producer of limestone the operation is by far the largest in Scotland.

Northern Ireland

Lower Carboniferous rocks in Northern Ireland include two thick limestone formations separated by more arenaceous and argillaceous material. The lower limestone unit, known as the Ballyshannon Limestone, consists of massive limestones over 300m thick in places, while the upper, known as the Rockdale Limestone or Dartry Limestone, may be over 200m thick. These are separated by the Carnteel formation, which consists largely of thick sandstones and shales with some limestone.

Carboniferous limestone outcrops mainly in a broad belt in the south-west of the province and in areas near Cookstown and Armagh (Figure 20). It is exploited at approximately 20 quarry sites, most of which are in County Fermanagh. In recent years annual production of Carboniferous Limestone in Northern Ireland has exceeded 2 million tonnes.

The largest quarry, at Cookstown in the Rockdale Limestone formation, produces material for the only cement making operation currently active in Northern Ireland. A semi-dry process is used with an annual capacity of 0.4 million tonnes of cement. Among other large producers, a quarry at Navan, Armagh, contains the only lime making facility in the province, the product of which is mainly used in lime-silica brick manufacture. The quarry also produces aggregates for concrete and ground limestone for agriculture. There is also a large quarry complex at Crievehill near Fivemiletown in Fermanagh: the products are mainly used in concrete, coated roadstone and concrete brick manufacture.

The remaining quarries produce mainly ground limestone for agriculture and coarse aggregate for concrete. Although some limestone is used for coated roadstone, particularly in the west, basalt is traditionally preferred for this purpose.

Dolomite is not produced in Northern Ireland, but workable deposits are thought to be present within the main limestone units in Fermanagh and Tyrone. The dolomitisation appears to be controlled by the presence of faults and by the Lower Carboniferous/Moine junction. Unfortunately the presence of a thick drift cover in many places has inhibited exploration, but the Geological Survey of Northern Ireland has located significant deposits near Belleek and Pettigo, County Fermanagh, and at Kildress Lower near Cookstown in County Tyrone.

Permian

Permian limestones and dolomites crop out in a narrow, easterly dipping zone which extends almost continuously over a distance of approximately 230 kilometres between Newcastle and Nottingham. In 1977 11.5 million tonnes were raised from this formation amounting to 11 per cent of the United Kingdom production. The formation, known as the Magnesian Limestone, is usually a dolomite or calcareous dolomite, although it may grade into a limestone in places. It is often worked for fill or sub-base in roads, the fines being used for agricultural purposes. Much less commonly it is used for concrete aggregate or coated roadstone. As a source of local dolomite for refractories, glassmaking or chemicals it is of unique importance.

Elsewhere in England there are thin deposits of Permian dolomite and limestone in the Vale of Eden, West Cumbria and Furness, but these contain no active workings and are probably of negligible importance as resources.

The Magnesian Limestone formed in a shallow sea, the coast of which was close to the western edge of the present Yorkshire/Nottinghamshire outcrops and somewhat further to the west of the outcrops in North-East England. After the limestones had accumulated there was a period of very high evaporation in which gypsum ($Ca\ SO_4.2H_2O$) was precipitated and the magnesium-rich residual sea-water gained access to the newly formed limestone causing dolomitisation.

As a result of the complexity of the processes of dolomitisation and dedolomitisation which, to a greater or less extent, have affected the Magnesian Limestone, variability in its composition is considerable, particularly near the outcrop. It contains dolomites and limestones, and includes rock strong enough to make good quality aggregates and material so weak that it resembles a sand. In some areas the rock is dense and frost resistant while in others it is highly porous and frost susceptible.

In North-East England, the limestones are divided into three formations. The Lower Magnesian Limestone, in which most of the quarries are located, forms the western part of the outcrop and is up to 73m thick in Durham. The Middle Magnesian Limestone which occupies a wide outcrop is over 120m thick in places but is replaced by anhydrite to the east. It includes an extensive barrier reef, approximately 30 km long and 1 km wide. The Upper Magnesian Limestone is a complex of deposits occurring along the coast, it includes the Concretionary Limestone, the Hartlepool and Roker Dolomite and limestones of the Seaham Formation (Figures 21 and 22).

In North Yorkshire, South Yorkshire, Derbyshire and Nottinghamshire the Middle Magnesian Limestone is absent and the formation is described in terms of Lower and Upper Magnesian Limestone.

In North-East England several quarries in the Magnesian Limestone produce a dolomite or calcareous dolomite which, although too soft for use as coarse aggregate in concrete, is often sufficiently frost resistant for use as road sub-base. Aggregate Crushing Values of about 27–29 are fairly typical and the quarried stone often includes poorly cemented material which gives rise to a high proportion of fines after crushing. Hence several quarries tend to produce a coarse aggregate together with fine material for agricultural purposes. An example is Marsden Quarry, near South Shields, which exports agricultural material to Northern Europe.

The three largest quarries in the area, Thrislington, Cornforth and Raisby are located close together near Coxhoe, Durham. Thrislington produces a high

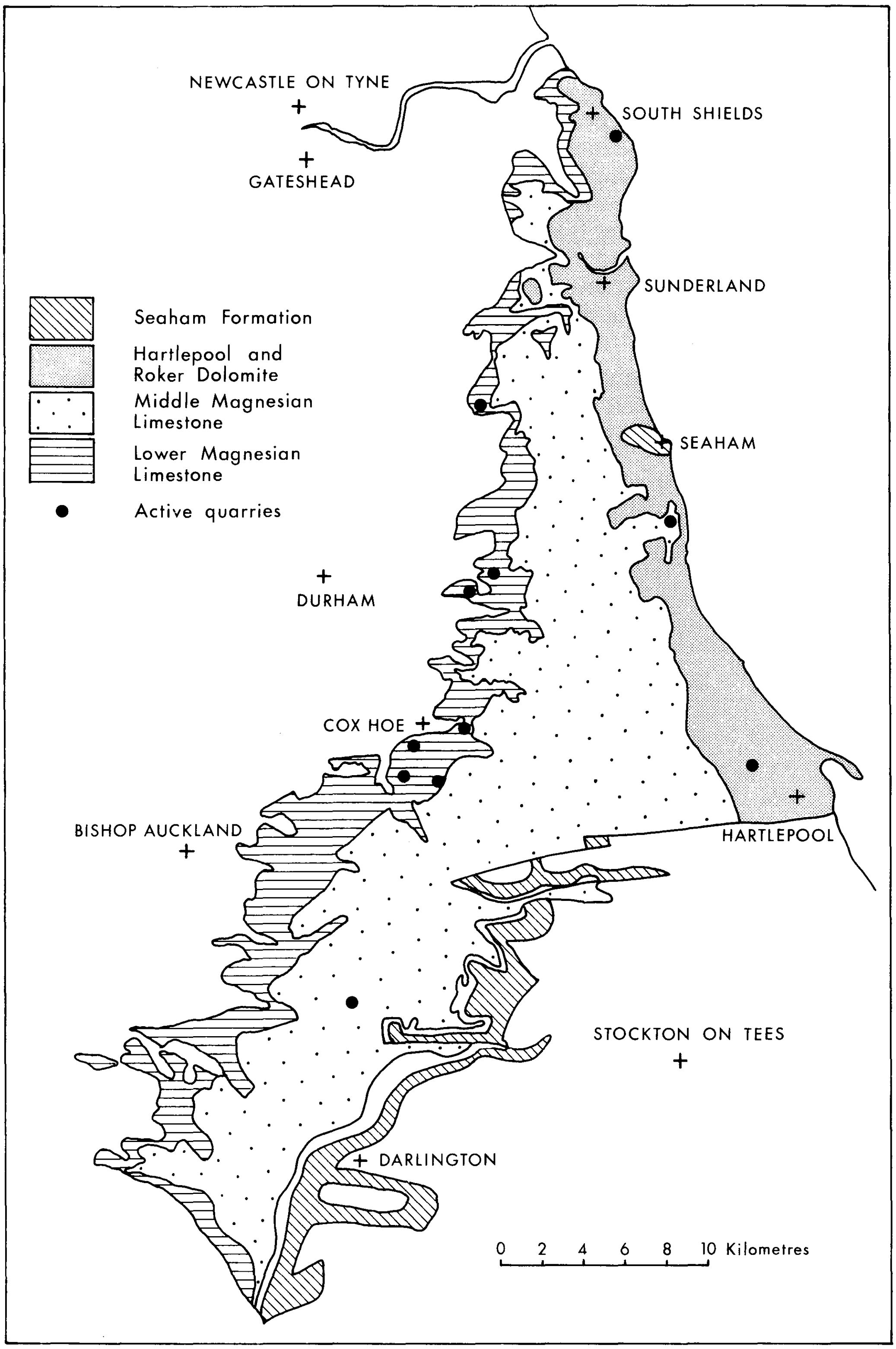


Figure 21 Magnesian Limestone in north-east England

grade dolomite used in the sea-water-magnesia plant at Hartlepool together with some flux and aggregate for concrete. Cornforth is mainly an aggregate producer. Raisby Quarry is unusual in that it consists of an upper layer of dolomite and a lower layer of hard limestone. The limestone is used mainly for roadstone and provides the only bitumen coated material produced from the Permian in North-East England, both the limestone and the dolomite are also used for flux.

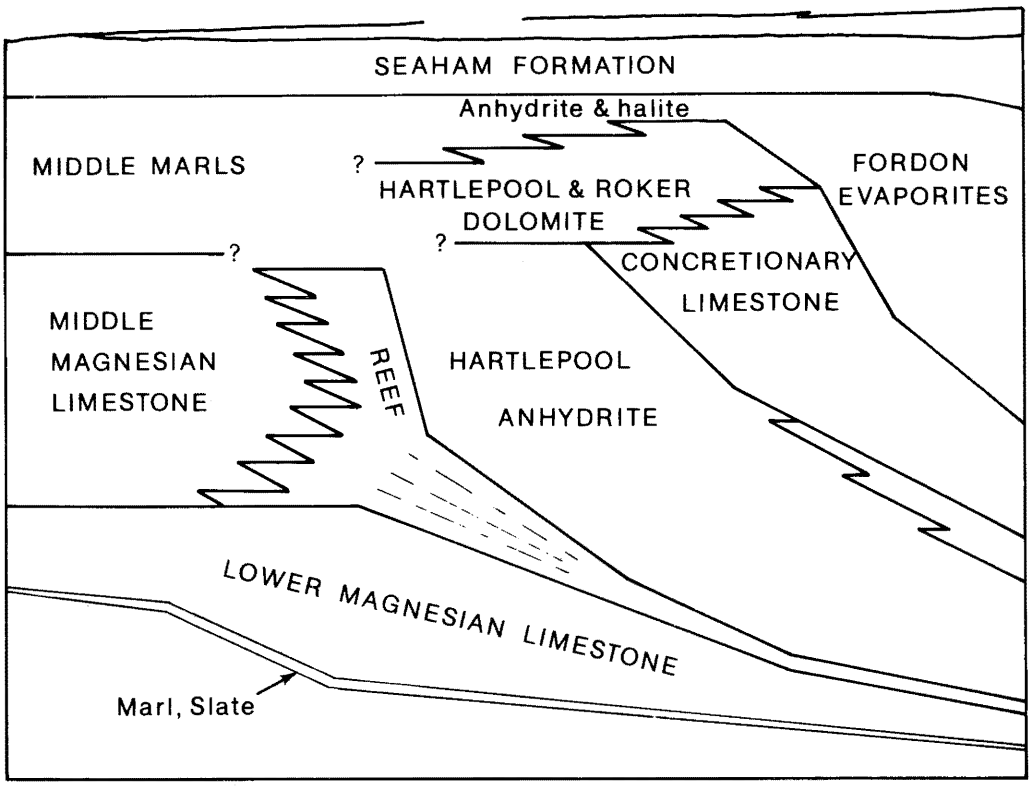


Figure 22 Diagrammatic W–E section showing the relationship between limestones and other formations in the Permian of North-East England. Reproduced by permission from 'The Geology of North-East England,' Spec. Publ. Nat. Hist. Soc. Northumbria, 1980.

In the Middle Magnesian Limestone, at Hawthorn Quarry, near Seaham, the extensive barrier reef forms a deposit of hard limestone which is surrounded by softer dolomitic limestone. Recent exploration beneath the hard limestone has indicated over 30m of unusually pure dolomite, by domestic standards, containing 31.7% CaO, 20.6% MgO, 0.5% SiO_2, 0.11% Fe_2O_3 and 0.12%Al_2O_3.

Other quarries in the area which produce dolomite include some workings in the Basal Permian Sands which in places extend into the lowest part of the overlying Lower Magnesian Limestone.

Many of the quarries in the Magnesian Limestone between North Yorkshire and Nottinghamshire produce fine dolomitic material for agriculture together with coarse aggregate for fill or sub-base. However in certain areas there are important producers of limestone, hard dolomite and high purity dolomite.

Production of limestone is largely concentrated in a group of four quarries in the Upper Magnesian Limestone some 3 to 6 km south of Knottingley. The material contains approximately 0.5% magnesia and is significantly harder than much of the adjacent dolomite. In two of the quarries the aggregate is acceptable for use in concrete after washing.

Further south, near Maltby two large quarries are located in relatively tough dolomite. One of these is the only quarry to produce bitumen coated roadstone from the Permian outside North-East England. Both quarries produce good quality concrete aggregate and have ready-mix plants on site: physical properties include: ACV 23, AIV 20, AAV 15, PSV 52, 10% fines 240 KN.

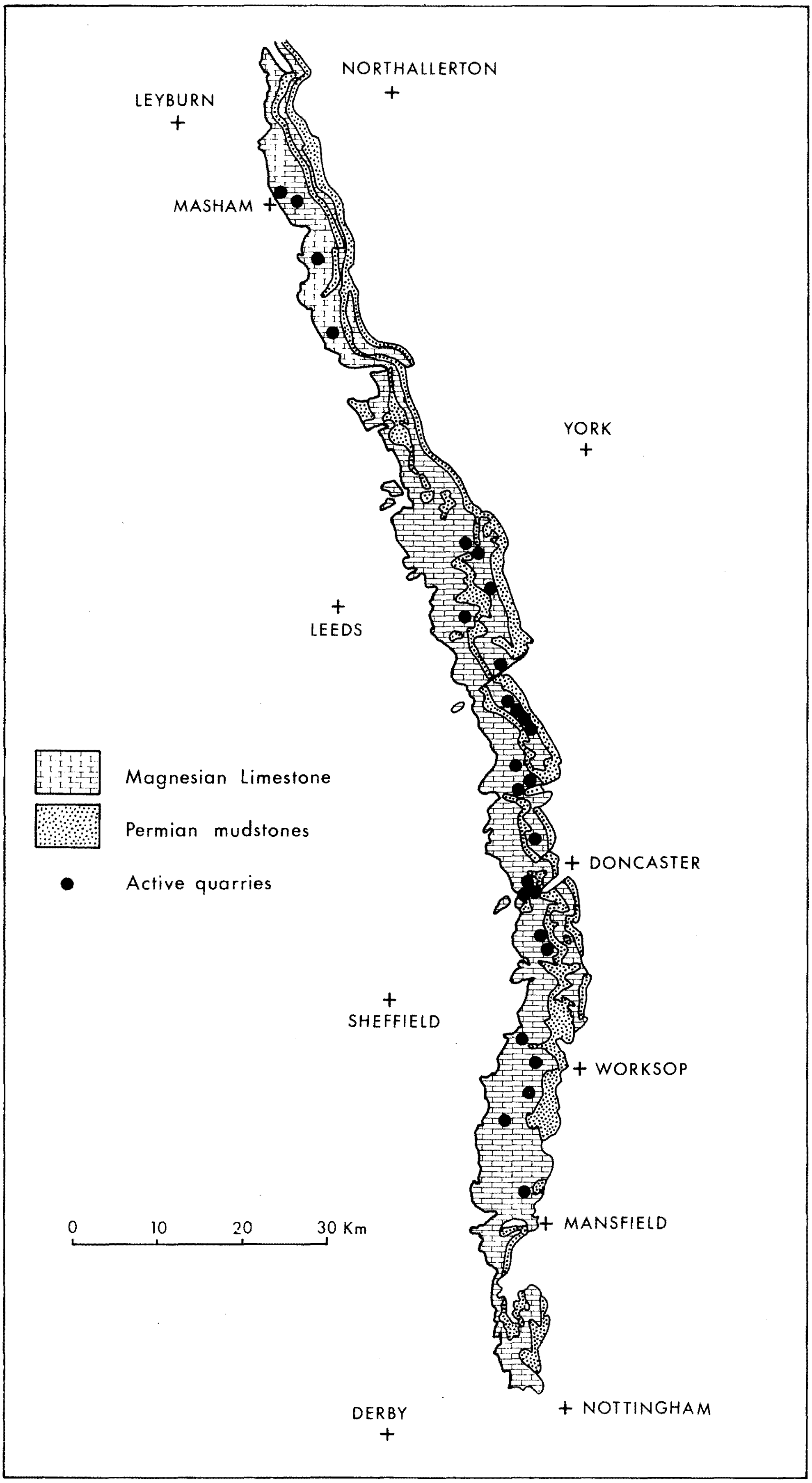


Figure 23 Magnesian Limestone in Yorkshire, Derbyshire and Nottinghamshire.

Dolomite of good chemical quality is produced from Warmsworth Cliffs Quarry on the River Don near Doncaster. Apart from some low-grade material sold for fill, the output is used entirely by Pilkington Brothers Ltd for glassmaking. The iron content is critical and is normally 0.20%–0.24% Fe_2O_3 which is close to the minimum currently produced from domestic dolomites. Cadeby Quarry, nearby, produces aggregate and some dolomite for use in blast-furnace sinter at Scunthorpe. Whitwell Quarry, near Worksop, produces calcined dolomite for metallurgical and refractory application (Table 39). Two other quarries in Derbyshire and Nottinghamshire produce aggregates, and there are some small building stone producers, not shown on the map (Figure 23), at the southern end of the outcrop near Nottingham. Building stone is also produced at a small quarry near Tadcaster.

Table 39 Analyses of dolomitic lime produced from Magnesian Limestone.

	Whitwell Quarry %	*Thrislington Quarry* %
CaO	57.0	62.0
MgO	39.0	35.0
SiO_2	0.75	0.53
Fe_2O_3	1.35	1.14
Al_2O_3	0.4	0.25
S (max)	0.05	0.05
CO_2	0.50	0.50

Source: Steetley Minerals Ltd.

Jurassic

The principal outcrop of Jurassic rocks in Great Britain extends almost continuously from Cleveland to Dorset, except that the Yorkshire outcrops are separated from those to the south by an area of attentuation or "axis" centred on Market Weighton. Similar, although less pronounced, "axes" affecting the lower part of the succession occur at Moreton-in-Marsh and in the Mendips.

The Jurassic is conventionally divided into three parts, Lower (Lias), Middle (Inferior and Great Oolite) and Upper. All divisions contain limestones or calcareous materials and the system as a whole is of importance as a source of cement, building stone and certain types of aggregate. However, most Jurassic limestone are oolites which tend to be porous; they are not dolomitic and contain little material of high chemical purity. As they have few properties of particular value to either the construction or manufacturing industry they tend to be worked where better quality coarse aggregates are difficult to obtain.

The Lias consists mainly of calcareous shale and is relatively unimportant as a source of limestone. However the typical succession of thin impure limestones and shales in the Lower Lias provides material suitable for cement making, and cement works have been established on the outcrop at Rugby and Southam, Warwickshire, and at Aberthaw and Rhoose, South Glamorgan, although these works now use additional calcium carbonate in the form of chalk or Carboniferous limestone.

The Lias contains deposits of sedimentary calcareous ironstone or marlstone such as Frodingham iron ore in the Lower Lias at Scunthorpe and the Middle Lias iron ores at Cleveland and Banbury. Some of this can be regarded as a ferruginous limestone and at Edge Hill the Banbury Ironstone is worked for building stone (Hornton Stone). Nearby it is also worked as a source of aggregate for use as fill. Frodingham iron ore is still used in iron making although its main function is now to act as an iron bearing flux in the treatment of high grade imported ores (Figure 24).

At present the only other workings in the Lias are in Somerset where building stone is produced on a small scale from thin limestone at the base of the Lower Lias and from the Upper Lias at Ham Hill.

The Middle Jurassic contains abundant limestones to the south of the Market Weighton axis. Between Kettering and the Humber the only limestone quarried at present is the Lincolnshire Limestone which frequently exceeds 30m in thickness. It provides several building stones known under such local names as "Ketton Stone", "Clipham Stone" and "Ancaster Stone" and is worked by some twenty quarries most of which produce material for fill or hardcore. At the base in the south, a thinly bedded fissile stone known as the "Collyweston Slate" has been used for roofing. In the Peterborough area, where there is a concentration of quarrying activity, some frost resistant material is produced suitable for use as sub-base and nearby, at Ketton, limestone and associated argillaceous material provides the basis for cement making.

South of Kettering the Lincolnshire Limestone is absent but a locally developed sandy limestone in the Northampton Sands, Inferior Oolite, is worked at Pitsford and Duston.

In Oxfordshire and southern Northamptonshire the limestones in the Great Oolite, which are up to 40m in total thickness, become of economic importance. They are worked, together with associated shales, near Woodstock for cement manufacture and there are other quarries at Brackley, Ardley and Burford which produce material for fill. Ground agricultural limestone is produced near Woodstock and a well known building stone occurs at Taynton.

In Gloucestershire, the Inferior Oolite thickens over a restricted area to reach a maximum of 100m near Cheltenham where it has been worked to produce such building stones as "Guiting Stone", "Cheltenham Building Stone, "Painswick Hill Stone" and "Campden Stone". It is still worked, largely for building stone, from some six small quarries in this area, although at Guiting, aggregate is also produced. The Great Oolite is worked in Gloucestershire mainly for aggregates and agricultural purposes together with some building stone. It includes a thin fissile stone known as "Stonesfield Slate", formerly used for roofing but now worked for aggregate. The material is unusual among Jurassic limestones in that it is reputed to be frost resistant and suitable for use in concrete.

Further south in Wiltshire, Avon, Somerset and Dorset, limestones are present in both the Inferior Oolite and Great Oolite, but working is not widespread, presumably because of the local availability of Carboniferous limestone from the Mendips. However there are small building stone quarries near Bath in the Great Oolite, locally known as "Bath Stone", and "Doulting Stone" is produced from the Inferior Oolite at Doulting near Frome. Some of the Carboniferous limestone quarries in the eastern Mendips work beneath a thin overburden of Jurassic limestone which is from time to time stripped off and sold locally for fill.

Overlying the Kimmeridge Clay, in the Upper Jurassic, the Portland Beds are an important source of limestone in Dorset and to a lesser extent in Wiltshire. In the Isle of Purbeck and the Isle of Portland, building stone has been produced traditionally from many small quarries which together probably still constitute the most important single source of building stone in the country. There are some workings in the Portland Beds in the Vale of Wardour, and in Sussex a sandy limestone from the Portland Beds is raised, from the base of a gypsum

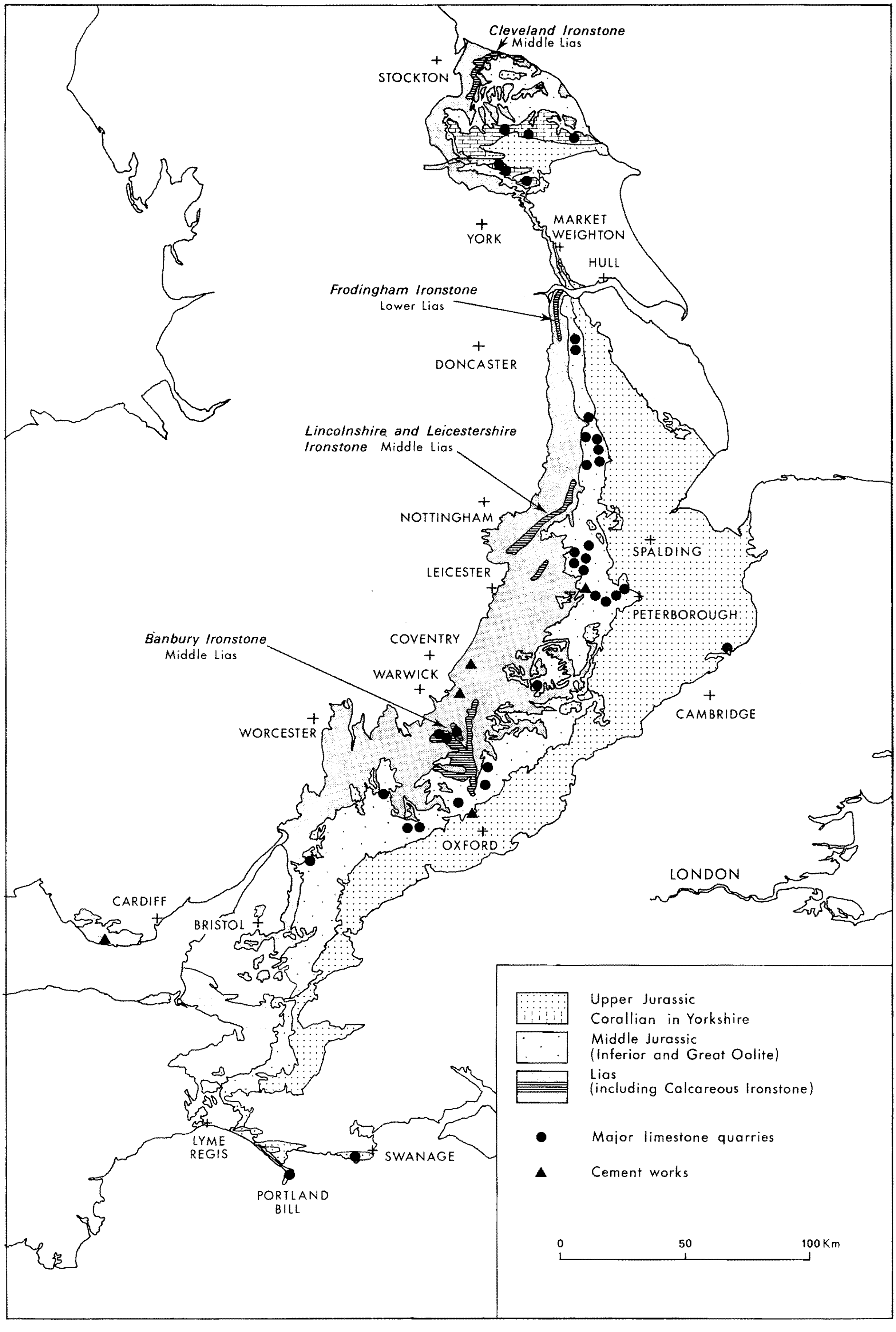


Figure 24 Jurassic outcrop and major limestone workings in England and Wales

seam at Mountfield Mine, for use as aggregate. The Purbeck Beds at the top of the Upper Jurassic contain some limestone which is exploited for building stone in the Isle of Purbeck.

Over much of its outcrop in East Anglia and Lincolnshire the Upper Jurassic consists entirely of clays. However, in Oxfordshire, Corallian limestones occur between the Oxford Clay and the overlying Kimmeridge Clay, but although these generally persist to Dorset, they are unworked.

In Yorkshire, north of Market Weighton, Corallian limestones are also present and form the basis of an important industry in the Vale of Pickering. Two of the quarries, Spaunton and Newbridge, produce a good quality material suitable for bituminous coating and concrete aggregate. The others mainly produce material for hardcore and agricultural purposes, and there is some production of building stone at Hovingham.

Cretaceous

The thick widespread development of Chalk in the Upper Cretaceous constitutes an important source of calcium carbonate. In contrast, Lower Cretaceous strata contains calcareous material only locally in the Hythe Beds in the Weald.

Lower Cretaceous

The Hythe Beds, part of the Lower Greensand, have a variable lithology, but in Kent and parts of Sussex they consist of alternate beds, approximately 0.7m thick, of a hard, bluish-grey sandy limestone ("rag") and a grey, loosely cemented, calcareous argillaceous sandstone ("hassock"). The material is quarried at three sites between Maidstone and Borough Green, Kent. The "rag" is frost resistant and is the only source of hard rock suitable for the more demanding aggregate uses in South-East England. Formerly, it was used for bitumen coated roadstone, but it is now used only for Type 1 road sub-base. The main problem in exploitation involves separating sandy "hassock" material from "rag" which is achieved by rejecting the fines by screening after crushing. Repetition of the procedure at successively finer sizes eventually gives a "rag" product suitable for use as limestone aggregate.

Upper Cretaceous

Chalk occurs extensively in the North and South Downs and extends from the south coast in Dorset to Flamborough Head, Humberside (Figure 25). Between 250 and 550m thick in most places, it consists mainly of finely divided calcium carbonate, composed of sub-microscopic fossil particles. To the west, in Devon, it thins to approximately 80m and becomes less pure, while in Northern Ireland where it is known locally as White Limestone, it is some 50m thick and is extensively overlain by Tertiary lavas (Figure 26).

Chalk is porous and, when saturated, commonly contains 18-25% absorbed water in southern England, depending on the clay content. In Humberside and Lincolnshire the Chalk is harder and contains only 7%–10% water, while in Northern Ireland it contains about 3% water and has the characteristics of a fairly hard limestone.

In southern England the Lower Chalk is up to about 60m thick and consists of an argillaceous lower part, the Chalk Marl, which is succeeded by more calcareous Grey Chalk. The Middle and Upper Chalk consist essentially of high grade calcium carbonate together with flints, which are particularly abundant in the Upper Chalk. Beds 0.5m thick, of relatively hard material known as "hard grounds" are sometimes grouped together to produce distinct hard rock bands

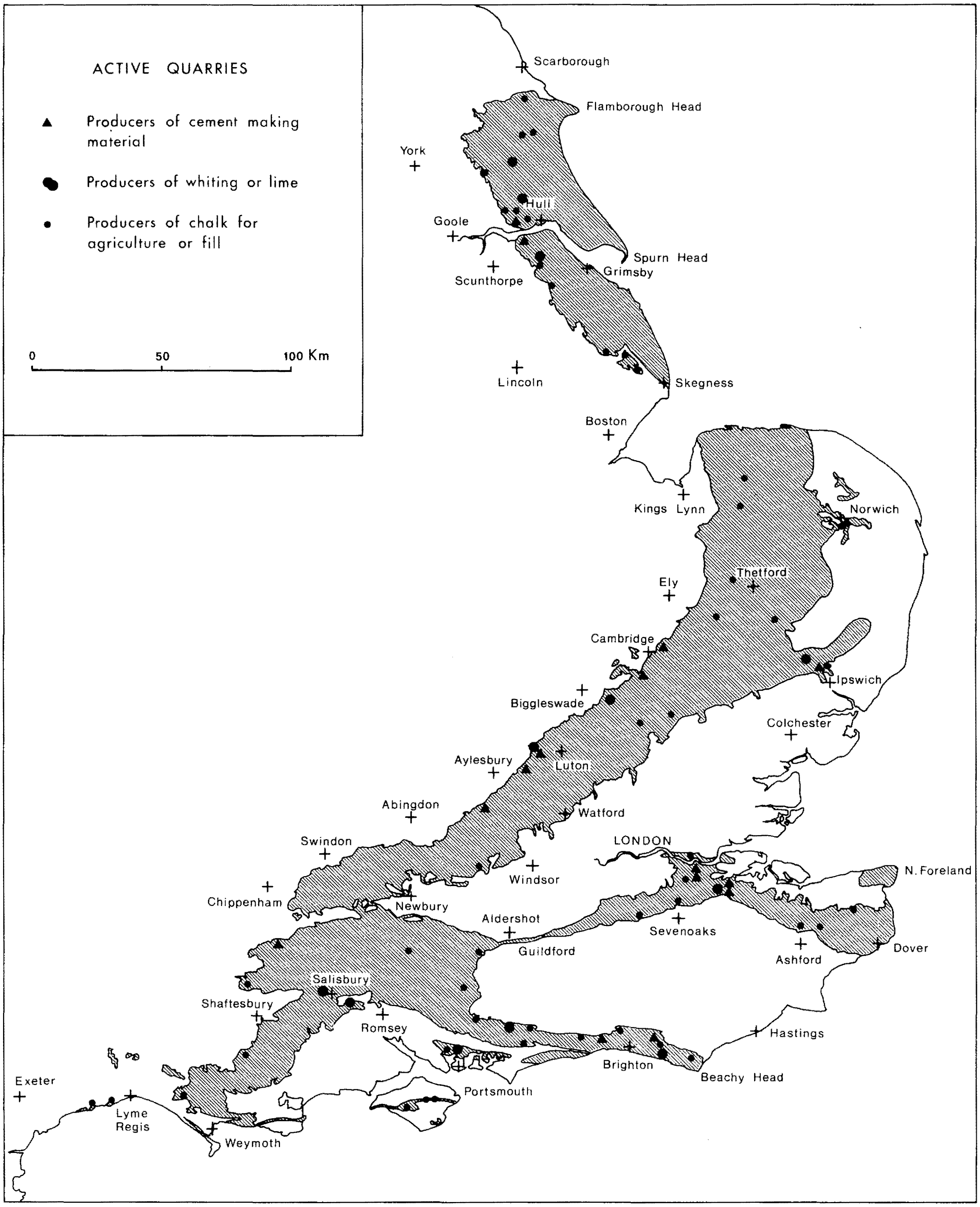


Figure 25 Chalk in England

with thicknesses up to 7m. Examples include the Totternhoe Stone in the Lower Chalk and the Melbourne Rock, which forms the boundary between the Lower and Middle Chalk. These formations have been used for building stone, but the material is not well suited for this purpose and is now unworked. Only the Beer Freestone in Devon, made up of comminuted shell fragments, is still worked on a small scale.

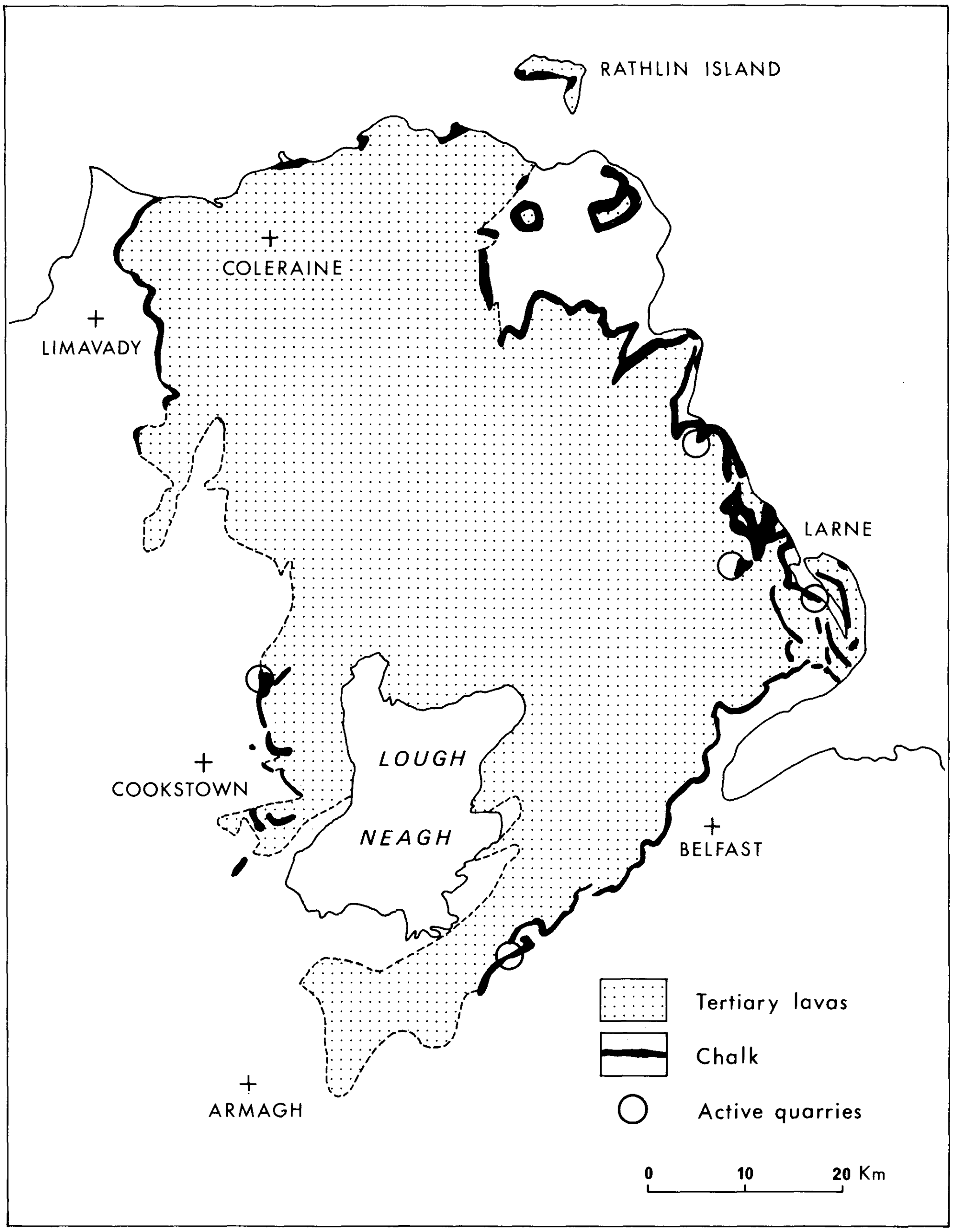


Figure 26 Chalk in Northern Ireland

In the Isle of Wight, the Isle of Purbeck and at Lulworth, the Chalk has been folded into a zone of very steep or vertical dips where there is a decreased moisture content, with a corresponding increase in hardness. The bulk density increases from less than 2 to about 2.6 as the dip increases from horizontal to vertical. The practical effect is that some quarries in this zone can produce material for hardcore, which is unusual in southern England.

In terms of volume the most important end use of chalk in southern England is in the manufacture of cement. The industry was originally established alongside the Thames near Dartford and Thurrock, and in the Medway valley near Rochester. Despite recent closures in Essex this area is still a major centre of the industry. At Dartford, the Northfleet works which was responsible for 19% of UK output in 1973, remains the largest cement producer in the United Kingdom, although capacity will be reduced in future. It uses Upper Chalk, worked from beneath a considerable overburden of Thanet Sand, together with London Clay from a pit in Essex which is transported under the Thames by pipeline as a slurry.

In the Medway Valley the Lower Chalk is exploited for cement making at Halling by a multi-bucket excavator working in a deep pit which is mostly under water, while nearby at Holborough another cement works exploits Lower and Middle Chalk together with some Gault Clay.

In the South Downs there is a cement works at Shoreham based on Upper Chalk and Gault Clay. At Lewes there is very small cement making operation using Lower Chalk.

Apart from a works at Ipswich, based on Upper Chalk and Boulder Clay, all other cement manufacturers in southern England are located close to the north-west facing Chalk escarpment which extends from Wiltshire through the Chilterns to beyond Cambridge. These works are based mainly on Lower Chalk which can be utilised to provide both calcareous and argillaceous constituents, although in some cases local Kimmeridge Clay or Gault Clay may also be used and some of the chalk workings may extend into the Middle Chalk (Table 6). Where the workings are entirely within the Lower Chalk, as at Chinnor, Oxfordshire, and Pitstone, Buckinghamshire, it is usual to mix more calcareous material from a high level quarry with more argillaceous material from a quarry at a lower level, the two materials being known as "high chalk" and "low chalk" respectively. The quarry at Kensworth, Dunstable, in the Middle Chalk, is exceptional in that its entire output is transported as a slurry in a pipeline to cement works at Rugby and Southam, which were originally located close to quarries in the Lias but now use a high proportion of chalk in their feedstock.

The majority of chalk workings in southern England are small operations producing material for agriculture. The extraction process involves digging the chalk and screening it to a size suitable for agricultural spreading. Unfortunately the high water content causes difficulties in working and particularly in screening, to the extent that most operations cannot function in wet weather unless artificial drying is used. Because of high fuel costs, operations tend to be intermittent and often cease altogether in winter. Such working difficulties of necessity limit production, and it is usual for individual chalk quarries in southern England to have annual outputs of less than 10,000 tonnes.

In southern England the Chalk has been carefully evaluated for application as whiting or filler where such properties as brightness or colour are of importance. In general there is a steady decrease in clay content towards the top of the chalk and the corresponding increase in purity leads in turn to an increase in brightness.

Immediately after the Cretaceous, a period of erosion removed Upper Chalk from some areas. In others, percolating groundwaters caused extensive contamination by foreign materials, particularly iron oxides, derived from overlying Tertiary and drift deposits. Hence resources of high brightness material are generally absent over such wide areas as the Upper Chalk outcrop between Newbury and Hertford, because the appropriate zone is missing, while in East Anglia the Chalk tends to have been adversely affected by deep staining. However, the Chalk in the eastern part of the Hampshire Basin, including the Isle of Wight and Portsmouth area, is generally favourable. Optimum material in southern England is probably located in the eastern part of Salisbury Plain, where two quarries, East Grimstead and Quidhampton produce high brightness calcium carbonate fillers for use in the paper industry.

In Lincolnshire, Humberside and North Yorkshire the Chalk was deposited under different conditions from those prevailing in southern England. It is divided into four formations; Ferriby Chalk, Welton Chalk, Burnham Chalk and Flamborough Chalk. The Ferriby Chalk (26m thick) at the base of the succession is flint-free, argillaceous and includes some red coloured marl known as the Red Chalk, otherwise it is comparable to the Lower Chalk of southern England. The Welton Chalk (44-53m thick) is relatively pure and contains flint nodules, while the Burnham Chalk (130-150m thick) is characterised by layers of tabular flints together with nodules. The Flamborough Chalk at the top of the succession consists of over 300m of relatively soft, flint-free chalk. The outcrops can be summarised in terms of a narrow zone of Ferriby Chalk along the western and northern edge of the escarpment, extending from Skegness to near Filey, and a broad basin of Flamborough Chalk occupying the area to the west of Hull and Middleton on the Wolds, to the north of Grimsby and to the south of Bridlington. The Welton Chalk and Burnham Chalk extend conformably throughout the remaining area. The Burnham Chalk, being harder, tends to form the higher ground including the promontory of Flamborough Head.

Working methods in northern chalk are mainly comparable to those found in conventional hard rock quarries and usually involve the use of explosives and crushers. Quarries can be worked in wet weather and the material is usually strong enough for use as hardcore and other aggregate applications where its susceptibility to frost damage is unimportant. For example at Flixton Quarry, near Scarborough, in the Burnham Chalk, aggregate with ACV 30, AIV 27 and 10% fines value of 120 KN is produced from material having a moisture content of approximately 6%. However, the Flamborough Chalk is sometimes sufficiently soft to be worked without explosives and is mainly used for agricultural rather than for aggregate purposes.

Cement production in northern chalk is now concentrated at a works on the south side of the Humber at South Ferriby, where Welton Chalk, Ferriby Chalk and the underlying Jurassic clays are used in a dry process. On the north side of the river, at Melton, a similar, although larger section of the Chalk was also worked for cement making until 1980. The essential difference between northern and southern chalks in cement making is that the northern material can be delivered to the works in a fairly dry form, suitable for treatment in the dry process. However flints are not easily removed and must, to some extent, be fed into the kiln with the chalk.

At Melton Ross, in south Humberside, Welton Chalk is exploited by Singleton Birch Ltd for lime used in steelmaking at Scunthorpe. Flints in the chalk are partially removed, before and after calcination, by screening.

Table 40 Analysis of chalk whitings

	1 %	*2* %	*3* %
$CaCO_3$	97.4	98.0	98.5
Al_2O_3	0.25	0.25	0.19
Fe_2O_3	0.09	0.08	–
MgO	0.30	0.25	0.23
SO_3	0.05	0.04	0.09
K_2O	0.04	0.01	–
Na_2O	0.04	0.01	–
acid insolubles	1.45	1.25	0.96

Sources:
1 Snowcal 7/ML, produced by Blue Circle Ltd, Melton near Hull. The product is approximately 52% finer than 3 microns.
2 Snowcal 8/SW, produced by Blue Circle Ltd, Swanscombe, Kent. The product is approximately 54% finer than 3 microns.
3 NP 100, produced by English China Clays Ltd, Quidhampton near Sailsbury. The product is approximately 44% finer than 1 micron.

Production of whiting from northern chalk is a long established industry, the material being sold traditionally under the name "Paris White" (Table 40). At present, material for this purpose is extracted from the cement workings at Melton, from a site at Beverley in the Flamborough Chalk owned by Queensgate Whiting Ltd., and from two sites near Lund owned by Microfine Minerals and Chemicals Ltd. Northern chalk whitings have a high brightness and a fairly low porosity which results in relatively low binder requirements and low absorption of oil.

In Northern Ireland there are six operating quarries which in recent years have produced a total of approximately 0.4 million tonnes annually. At the largest, Magheramorne, chalk was extracted from beneath a thick overburden of basalt, mixed with marine dredged alluvium and used for cement making. However the cement works is now closed due to lack of demand. At Glenarm, the Eglinton Quarry produces an ornamental white aggregate for use as exposed aggregate in concrete panels, as aggregate in white concrete and as pebble-dash chippings. Finer sizes are used in animal foodstuffs, as a filler in asphalt and road marking paint. There is also some production of fine ground whiting for use in polymers, paints and adhesives. The other operations mainly produce ground limestone for agriculture.

Quarrying of Irish Chalk is by methods conventionally employed in the working of hard limestone and involves drilling, blasting and crushing. Flints are universally present and because of the high strength of the chalk, no satisfactory method, other than hand picking, has been developed for their extraction. However, during fine grinding the more resistant silica tends to concentrate in the coarser fractions which allows for the production of relatively pure fine calcium carbonate.

Published data suggests that the material from Glenarm has a crushing strength of 40–50 MN/m^2, an AIV of 22–23 and a water content of 1.35%. It is frost resistant and makes a satisfactory concrete aggregate.

Post Cretaceous

With the exception of some beach sands containing shell fragments and a Tertiary limestone in the Isle of Wight there are no limestones of economic significance younger than the Cretaceous.

The Oligocene in the Isle of Wight contains a fresh-water limestone, some 2.5–7.5m thick, which although unworked at present, was formerly of importance as a building stone and was once used for cement making at Brading.

Beach sands, containing sufficient shell fragments to be valuable as sources of calcium carbonate, occur extensively in the north and west of Scotland and to a lesser extent in west Cornwall. Individual deposits are usually small and thin and subject to disturbance by storms. Although pure shell sand has a very high calcium carbonate content, deposits are usually variable in quality. Nevertheless, in several remote areas, shell sands constitute the only local source of easily worked calcium carbonate and they have been extensively used for agricultural lime in the past.

In Scotland, shell sands occur on beaches in the Outer and Inner Hebrides, on the mainland in Ardnamurchan, Wigtown Bay and Sutherland, particularly near John o' Groats. They are also of importance in Orkney and to a lesser extent in Shetland. At present they are worked only on the Isle of Barra, in the Outer Hebrides, for use in concrete facings on buildings and in poultry grit.

In Cornwall, beach sands containing approximately 90% calcium carbonate are worked in St Ives Bay for use mainly in local agriculture.

TECHNOLOGY

Extraction

Hard limestone, for uses other than as building stone, is usually extracted in open quarries divided into one or more benches 10–20m high. Overburden such as soil, glacial drift or unsuitable rock is stripped from the top bench with a scraper or dragline to expose a limestone surface on which machinery can work. Subsequently a line of vertical or inclined holes is drilled parallel to, and to the same depth as, the face. The holes, spaced at calculated distances from the face and each other, are charged with a nitro-glycerine-based explosive or a mixture of ammonium nitrate and fuel oil. A short delay in detonation between successive holes results in an attenuated shock wave which minimises the vibrational effects of blasting on the surrounding area. After blasting, the broken rock is usually picked up by a front-end loader or mechanical shovel and transferred into large rubber-tyred trucks for transport to a crushing plant.

In some well-jointed limestones, explosives are dispensed with in favour of "ripping", in which a tracked machine equipped with a rear mounted single tooth loosens the rock sufficiently for it to be picked up with an excavator. The advantages of the method are largely environmental in that ground vibration and flying fragments are avoided.

Problems in limestone quarrying can arise when cavities carrying underground streams are encountered. The presence of deeply dissected surfaces, associated with limestone weathering, may also cause difficulties with face stability and in predicting the effects of blasting; infilled solution cavities can sometimes lead to product contamination. Environmental factors involved in mineral exploitation have recently been described by Down and Stocks (1977).

Chalk working in southern England often involves the use of techniques which are more usual in agriculture than in mining. Chalk tends to be extremely weak and porous and can absorb up to 25% water. When saturated it is impossible to screen or process, hence it must either be worked in dry weather, artificially dried, or mixed with water and treated as a wet slurry. In many of the smaller workings chalk is broken using a disc harrow or rotavator and allowed to stand until it is dry enough to be picked up with a front-end loader for treatment in a screening plant, which rejects flints and produces agricultural lime without artificial drying. Such workings cease altogether in winter and can operate only intermittently in summer. Variations involve storing newly excavated chalk in open stockpiles or covered sheds until it is dry enough to screen. In some workings, material is allowed to stand in the open through a winter so that frost action can break the chalk and allow easy drying. However, all these methods result in intermittent working. In continuous operations, oil-fired drying equipment is invariably used.

Cement production based on chalk requires relatively large amounts of material on a continuous basis and extraction may be by means of continuous bucket excavators if the chalk is soft, otherwise face shovels are used.

Limestones intended for use as building or ornamental stone are usually worked by traditional methods. The aim is to produce a block of approximately 2m x 1m x 1m dimension which can then be sawn or split to the necessary sizes. Blocks are extracted either by using wedges (plug and feather) to open out joints or holes produced by drilling, or by using a gunpowder type explosive which loosens the rock without creating internal weaknesses in the blocks.

Underground mining is occasionally resorted to where suitable limestone is covered by thick overburden. It has been carried out extensively in Scotland where Carboniferous limestones occur as thin seams which are rapidly carried beneath thick overburden by relatively steep local dips, although only one mine operates in this area at present. At Middleton, Derbyshire, there is a large operating mine where the Bee Low Limestones are extracted from beneath inferior quality material, and at Mountfield Mine, Sussex, limestone is produced from a gypsum mine. Otherwise there are no active underground workings in the United Kingdom although areas of previous activity include the Wren's Nest at Dudley, where Silurian limestone was extracted for flux, and two mines which produced Bath Stone and are now used for underground storage at Corsham and Monkton Farleigh, Wiltshire. The technology of limestone mining has been described by Stocks (1979).

Limestone mining makes use of the pillar and stall principle in which a series of multiple horizontal headings with cross cuts are driven into the bed. Approximately 25–50% of the excavated space is left for support as square or rectangular pillars, located at regular or random intervals. In addition a suitable thickness of limestone is retained in the roof to protect the workings. Extraction involves blasting in the headings after which the broken material is loaded into trackless vehicles for transport to the crusher. Centre to centre spacing of the pillars depends on the natural arch which the limestone is capable of maintaining, while the cross sectional area of the pillars is a function of the loading they carry. Headroom is governed by the thickness of the bed. Hence, a prime consideration is that the bed should be thick enough to allow the easy access of machinery and the use of a trackless haulage system. However, spacing between pillars, under normal circumstances, does not place any restriction on the use of conventional machinery. Vehicle access by horizontal or inclined tunnel is clearly desirable and entry to the mine is always by this method in Great Britain, although shafts are used abroad. Vein calcite mining is by methods normally used in fluorite or barite production, which may involve opencast working along the outcrop of veins or underground workings with shaft access.

Processing

Processing of limestone for use as aggregate and some industrial purposes involves crushing and screening operations designed to produce relatively coarse material in a specified size range with a minimum production of fines. In some instances, such as the production of material for agricultural use or asphalt filler, very fine material is specifically required. Specialised types of processing are used in the cement industry to prepare feed for the kilns and in the whiting or filler industry where very fine material within close size limits is needed.

In many large limestone quarries, primary crushing is carried out by gyratory crusher, such as at Merehead, Somerset, where a single machine of 3000 tonnes per hour capacity is used, or by an impact crusher of the rotary hammer type. Impact crushers are characterised by a fast moving rotor, with hammers attached, which strike some of the rock fragments, shattering them, and flings other fragments against an impact plate where further breakage occurs. They are widely used in limestone treatment because the non-abrasive material does not cause the excessive wear encountered with siliceous rocks. In some quarries, particularly those worked on a modest scale or which treat an impure, more abrasive limestone, a jaw crusher may be used for primary crushing.

The primary crusher is usually protected by a coarse screen, or grizzly, which is used either to reject material too large for the machine or to reject fines which contain impurities or do not require crushing. The rejected material may be treated subsequently but, particularly in the case of fines, it is often sold without further processing as a relatively inferior product known as scalpings or quarry waste.

After primary crushing, the product, which has usually been reduced to below 100–300mm in size, is delivered to a stockpile capable of accommodating several weeks output, which enables the quarry and plant to function independently over limited periods.

Material recovered from the stockpile passes to secondary and tertiary crushing operations with associated screening, to produce the desired size ranges. In limestone production most secondary or tertiary crushers are either rotary hammer mills or cone crushers. Fine material below approximately 3mm diameter resulting from coarse aggregate production is usually sold, perhaps after further treatment, for such purposes as agricultural lime, asphalt filler or fine aggregate. However, in areas where limestone is scarce, coarse aggregate is derived from other sources and the limestone is often completely reduced by ball milling for sale as fine material.

In chalk processing, when the material is worked only in dry conditions, a simple screening operation is sometimes sufficient to produce a fine product for agriculture. Otherwise, where the chalk does not disintegrate easily or is in a damp condition, it may be treated in an impact crusher. Northern and Irish chalks are usually treated by methods applicable to limestones generally.

Techniques of reduction to very fine sizes in whiting production vary in detail, but basically they involve either "wet" or "dry" methods depending on the raw material. Southern chalks are treated by a wet process in which the raw material is fully dispersed in water. After the flints have been separated, the slurry passes through hydrocyclones which exclude coarse particles. The product is then dewatered by tank settlement, followed by vacuum filtration. Finally it is subjected to dry milling and air classification. Northern chalks and hard limestones are dried in rotary kilns before being milled and air classified under controlled conditions.

Size reduction into the finest ranges of natural whitings (approximately 80–90% passing 2 microns) is a difficult and mechanically inefficient operation. Hence the cost of producing fine particles increases disproportionately as the size is reduced.

Manufacture of lime

To provide lime for agriculture, limestone was traditionally mixed with coal or wood for burning in small batch kilns or vertical kilns, and derelict remains of this industry are fairly common near limestone outcrops. However, transport improvements in the last century led to the abandonment of the very small local kilns and in the last fifty years the improved availability of cheap ground limestone has led to a decline in the use of lime or hydrated lime in agriculture with consequent further reductions in the number of producers. At present, therefore, lime burning is centralised at a few large plants which supply material mainly for industrial purposes. The industry uses either large vertical kilns, rotary kilns or, more recently, rotating hearth kilns.

Vertical kilns are traditional in lime making and many different types have been used. They consist essentially of a vertical cyclinder with a refractory lining, which was originally charged with coal and limestone but is now often heated by means of an oil or gas burner. Limestone enters the kiln at the top, into a storage zone, and then slowly sinks through preheating, calcining and cooling zones before being discharged at the base. The presence of large voids in the charge is necessary to ensure circulation of hot gases and uniform heat transfer, hence it is usual to exclude material finer than 50mm from vertical kilns, and at Tunstead Quarry, for example, a –250 +125mm material is the normal feed. However, the large pieces of limestone are slow to calcine because of low thermal conductivity and attempts to accelerate the process by raising the temperature can lead to overheating of the surface lime and yield a product of low reactivity. Conversely, long residence times can lead to excessive contact between the newly formed lime and the combustion products causing absorption of sulphur, which is undesirable in lime used in steelmaking. Hence the main problem in shaft kiln operation is connected with the uniformity and purity of the product, although heat efficiency is usually good and improvements in shaft design and the use of low sulphur fuels enable many shaft kilns to produce an adequate product.

Rotary and rotary-hearth kilns are used with relatively small sizes of limestone (for example –40 +20mm material is fed to both types of kiln at Tunstead) the quality of the lime is easier to control than in shaft kilns and there is less tendency to absorb sulphur from the fuel.

Rotary kilns are similar to cement kilns in principle, except that they operate at a lower temperature. Because of the tumbling action it is impractical for them to treat coarse material and they tend to be less thermally efficient than other types. However one of the newer types of kiln is said to combine the advantages of rotary and vertical systems. It comprises a vertical preheater feeding a rotary kiln which discharges into a vertical cooler. This arrangement avoids the high exit gas temperatures associated with ordinary rotary kilns and is said to have a heat consumption comparable with a vertical kiln.

Rotary-hearth kilns are relatively new and feature a circular refractory hearth, rotating at speeds between approximately 2 and 0.3 revs/hour, which is heated in separate zones. This arrangement is thermally efficient, allows for sensitive control and enables various sizes of stone to be calcined without overburning.

Calcination of dolomite is now carried out entirely by use of rotary kilns, although vertical kilns were used until recently at Taff's Well and a single vertical kiln is still used at Whitwell for the production of dead-burned dolomite from previously calcined material.

After calcination some lime is hydrated for sale as calcium hydroxide. This can be carried out by mixing quicklime with water in a continuous slaking unit to produce a lime slurry or putty, but more often is effected under controlled moisture conditions to produce a dry calcium hydroxide powder that can be packed in paper bags.

Cement manufacture

Portland cement is made from a mixture of calcareous and argillaceous materials in the approximate proportions 76% to 24% respectively. These are comminuted and mixed intimately in the required proportions. The mixture is then burned in a kiln, cooled and the resulting clinker ground with a small amount of gypsum, to a fineness appropriate for the desired reaction in concrete formation.

Because of the ease with which chalk and clay could be converted to a uniform slurry, it was possible with primitive equipment to produce an intimate mixture of these materials with the required composition and consistency for cement making. Consequently, in the last century, before the availability of grinding and mixing equipment suitable for use with hard limestone, chalk was the essential raw material in cement making and the industry became concentrated along the Thames and Medway where it was readily available. As it eventually proved almost impossible to treat the sticky wet chalk and remove the abundant flints other than by a slurry method, the wet process became standard. In practice the chalk and clay are comminuted and mixed by being fed into wash mills which are circular tanks some 7m–10m in diameter and 2m deep, stirred by rotating harrows. The feed is converted into a smooth slurry which leaves the wash mill through a screen in the wall of the tank, while the flints sink to the bottom and are removed periodically, or, if abundant, may be removed in a separate rotary drum washer.

The resulting slurry, containing approximately 60% solids, passes to a rotary kiln which consists of a long cylindrical steel shell, possibly 200m long and 5.5m in diameter, lined with refractory bricks and mounted at an inclination of about 1 in 30 on roller supports so that it can rotate at approximately 1 revolution/minute. The kiln is fired by a jet of pulverized coal, oil or gas injected axially at the lower end. On entering the kiln the water in the slurry is first driven off in a drying zone and the feed gradually forms into pellets. In the calcining zone the temperature rises above 900°C and carbon dioxide is driven off, after which there is a final burning zone where clinker is formed at a temperature of about 1500°C. The clinker is then allowed to cool to about 60°C for handling and storage.

To improve heat transfer in the drying zone and enable the heat in the gases to be used efficiently, a system of chains is hung from the shell of the kiln. As the kiln rotates the chains become covered with slurry and expose a large liquid surface to the gases. By this means, and sometimes also with baffles and/or cruciforms, the temperature of the exit gases from the kiln can be lowered to about 180°C, which is just above dew point in the subsequent cleaning and venting stages.

With the introduction of efficient grinding mills it became possible to make cement from hard limestone and shales. However, early attempts to treat these raw materials by feeding them in a dry state into long cement kilns were unsatisfactory. The exit gases had a very high dust content, and their temperature was so high that the process had a lower thermal efficiency than the wet process. Consequently the wet process originally developed for chalk, was extended to treat all types of raw material and, in the United Kingdon at least, it became the standard cement making process until the late 1950s.

Developments in cement making over the last twenty years have been directed towards the introduction of an effective dry process, and improvements in the thermal efficiency of the wet process.

In one variant of the wet process, known as the semi-wet process, the slurry is filtered to reduce the water content to 18–20% after which the filter cake is formed into nodules and fed to a preheater before being introduced into the calcining zone of a short kiln. In the dry process, improved heat exchange and dust control has been achieved with a suspension preheater, which involves feeding the dry, raw meal as a powder into a series of cyclones that receive hot exhaust gases from the kiln. Another method, known as the semi-dry process, involves wetting the raw meal to a moisture content of 12–14% and forming pellets for feeding to a preheater in which the exhaust gas temperature can be reduced to about 150°C.

In the choice of process, much depends on the original nature of the raw materials. With soft materials such as southern chalk, which can be dispersed as a slurry and separated from flint with little power, the wet or semi-wet process still has advantages. However the use of hot gas-swept mills (ball mills, tube mills and autogenous mills) now enables some chalk-based raw materials, containing up to 14% moisture, to be ground, mixed and prepared as raw meal for the dry process. For example, a dry process operates at Pitstone, Bucks, based on a flint-free material from the Lower Chalk. Also semi-dry process operates at South Ferriby using northern chalk and clay, and recently semi-wet processes have been introduced at Rochester and Southam to conserve energy in existing operations based on southern chalks.

Energy considerations

The calcination reaction ($CaCO_3 \rightarrow CaO + CO_2$), which is fundamental to lime and cement manufacture, is one of the most endothermic encountered in large scale industrial processes. Theoretically the heat for this reaction is 1.62 GJ/tonne of calcium carbonate at the decomposition temperature of 898°C (assuming atmospheric pressure of carbon dioxide). In addition, 0.85 GJ/tonne are required to raise the temperature of limestone to decomposition point, giving a total energy requirement of 2.47 GJ/tonne of limestone or 4.4 GJ/tonne of quicklime which may be compared with a heat content of coal of 22–32 GJ/tonne. In the case of dolomite, the calcination reaction is slightly less endothermic and proceeds at a slightly lower temperature. The total theoretical energy requirement is approximately 2.10 GJ/tonne of dolomite or 4.02 GJ/tonne of calcined dolomite.

In practice there are heat losses from the sides of kilns and in exhaust gases, and decomposition temperatures vary with the composition of solids and gases in the reaction. Heat is also required to dry the limestone and although this may be small in the case of non-porous limestone, it is higher for chalk and higher still in the case of wet slurries fed to cement kilns. In cement making there are the additional factors of a higher operating temperature and of shale or other materials in the feed which reduce the lime content and enter into the reaction. Also in both lime and cement making there are ancillary processes and services which add to the overall energy requirement.

The actual energy consumed by cement plants, according to the process, is given in Table 41.

Table 41 Typical heat consumption (GJ/tonne) for cement kiln only, 1979.

Wet process	
Long kiln	6.5
Semi-wet process	
Preheater and short kiln	4.9
Dry-process	
Long kiln	5.2
Suspension preheater and short kiln	3.8
Semi-dry process	
Grate preheater and short kiln	3.7

On the basis of total energy consumption in the form of coal, gas, oil and electricity, the cement industry used 96.5 x 10^6 GJ in 1978 amounting to 5.1 per cent of the total national industrial energy requirement, or an average energy consumption of 5.8 GJ/tonne of finished cement.

Traditionally the United Kingdom has favoured the wet process because of technical factors and the presence of relatively cheap coal. However, the rapid rise in fuel prices in 1973 and the subsequent decline in cement production has led some of the more energy intensive wet process works to close and others to convert to semi-wet processes. Thus total energy consumption in 1978 was only 72% of the 1973 figure and energy consumption per tonne of cement had improved in the same period by approximately 12%.

In the lime industry, it is estimated that the average consumption of energy was 5.7 GJ per tonne of lime (CaO) produced in 1976. However in response to increased fuel prices the less thermally efficient kilns are being closed or replaced and it is expected that consumption will fall to approximately 4.7 GJ per tonne by the mid 1980s. Total production of lime in 1978 was approximately 2.6 million tonnes. The corresponding figure for calcined dolomite is not available but may be estimated at 1.0 million tonnes. Very approximately 20 million GJ were therefore consumed in calcination of limestone and dolomite in 1978 and it would seem that the cement, lime and dolomitic lime industries together are responsbile for some 6 per cent of the national industrial energy requirement.

PRICES AND OTHER ECONOMIC FACTORS

The cost of limestone, like that of other aggregates, is strongly influenced by transport charges. As an approximate guide to 1980 prices a cost of 3–4p per tonne km can be assumed for road transport in loads of at least 10 tonnes with empty return journeys. Haulage charges tend to be high in congested urban areas and lower for longer journeys on motorways in larger vehicles. Increasing quantities of aggregate are being carried by rail, where charges are generally lower than road for distances in excess of approximately 100km, although rates vary with each contract.

Prices for crushed stone are strongly influenced by the amount of treatment which the product has received and by local marketing factors. In 1980 a typical limestone aggregate quarry in Gloucestershire was selling ex-pit graded aggregates for £2.50/tonne, Type 1 Sub-base for £2.00/tonne, 100mm crusher run material for £1.50 per tonne and 50mm scalpings for £1.30 per tonne. At the same time material from Somerset was being sold at a Basingstoke rail terminal for the following prices: graded aggregates £4.50/tonne, Type 1 Sub-base £4.29/tonne, 3mm fines £4.50/tonne, 13mm scalpings £3.60/tonne.

Cement and lime are relatively expensive particularly when sold in small amounts. In 1980 a major producer quoted prices of approximately £25 per tonne ex-works for both quicklime and hydrated lime in bulk tankers and another quoted £38 per tonne ex-works for cement in 50 kg bags in minimum loads of 10 tonnes. Comparable retail prices were £3.59 per 50 kg bag for cement and £2.61 for 25 kg bags of hydrated lime.

The price of whiting and filler depends essentially on the fineness, of the product. In 1980 Chalk BP for use in baking was quoted at £25 per tonne, while whiting for general use as filler or extender was £21 per tonne. However, very fine, high quality material used in paper or pigments was being quoted at prices between £70 and £80 per tonne.

LAND USE

According to a Department of Environment survey, 10,700 hectares of land in England in 1974 were covered by planning consents for the extraction of limestone, approximately half of which was already affected by quarrying operations, and 60% of the total area was contained in only six counties in England as follows: Derbyshire 14.5%, Somerset 13.5%, North Yorkshire 11.7%, Durham 7.9%, Cumbria 6.4%, Avon 6.3%. This reflects the importance of Carboniferous limestone which accounts for the greater part of the consents in all the counties except Durham where exploitation of Permian limestone is of more importance. Comparable data is not available for Scotland, Wales or Northern Ireland.

Planning consents for the extraction of chalk extend over 3,700 hectares in England, approximately 58% of which is already affected by workings. 78% of the total is in six counties, Kent 23.7%, Humberside 15.3%, Bedfordshire 14.1%, Essex 12.0%, Cambridgeshire 8.2%, Buckinghamshire 4.5%. The distribution is mainly the result of the location of cement workings. The high totals in Bedfordshire and Essex represent planning consents adjacent to cement works which have closed in recent years.

Most of the planning permissions covering mineral workings contain conditions to ensure that the site is effectively rehabilitated after use and does not become derelict. However some of the older permissions are defective in this respect and in the 1974 survey, of the area covered by planning permissions for mineral workings, only 55% of limestone and 80% of chalk permissions had restoration conditions attached.

Because Carboniferous limestone forms attractive scenery, a relatively large proportion of its outcrop is included in National Parks or Areas of Outstanding Natural Beauty. These include the Peak District National Park, the boundary of which was drawn to exclude the main concentration of quarries in the Buxton area, although the major resource of high grade limestone in the United Kingdom remains in the Park. The Yorkshire Dales National Park also contains a large limestone industry, although the extent of high quality material is less well known than in Derbyshire. The Pembrokeshire Coast National Park contains resources of Carboniferous limestone and the North York Moors National Park includes some Jurassic limestones.

Areas of Outstanding Natural Beauty including Carboniferous and older limestone include Arnside and Silverdale, Northumberland Coast, Gower, Mendip Hills, South Devon, Wye Valley, Shropshire Hills and Anglesey. Jurassic limestones and Chalk are included in the following Areas of Outstanding Natural Beauty: Cotswolds, Dorset, Isle of Wight, East Hampshire Sussex Downs, Kent Downs, North Wessex Downs, Chilterns, Norfolk Coast, and Lincolnshire Wolds.

Because of the amenity value of National Parks and Areas of Outstanding Natural Beauty, planning permission is usually more difficult to obtain and conditions attached to consents are more onerous than in other areas. Even outside the protected areas, limestones tend to form attractive countryside where there is often a reluctance to allow quarrying.

The amount of land consumed by individual quarries varies according to depth and output. The three largest quarries with nominal outputs of approximately 5 million tonnes a year are Tunstead Quarry, Buxton, owned by ICI; Merehead Quarry, Shepton Mallet, owned by Foster Yeoman and the chalk workings at Northfleet, Dartford, owned by Blue Circle Ltd. In addition there are approximately ten quarries with outputs consistently over 1 million tonnes a year, mainly in Derbyshire and Somerset. Otherwise, of the 400 or so remaining limestone and dolomite quarries, most have outputs in the range 0.1–0.5 million tonnes a year. The outputs of building stone quarries are much smaller. In addition there are approximately one hundred workings in the Chalk, including some large-scale operations serving 14 chalk-based cement works. Remaining chalk workings mainly produce material for agriculture, and have outputs in the range 50,000–5,000 tonnes a year.

The larger quarries cover extensive sites, for example the planning permission at Merehead Quarry extends over 60 hectares and at present it is worked to a depth of 30m although eventually working could extend to 75m. At Tunstead Quarry, the site is of comparable size and the working face, approximately 2 km long, varies in height between 40 and 60m. Yields per excavated acre are in general higher for limestone than for most other types of mineral working, reflecting in general the thickness of many Carboniferous limestones and the easy working conditions. However the yield of over 1 million tonnes per hectare achieved at Tunstead is uncommon, although more deep quarries will probably develop in future.

Problems in land-use planning associated with limestone working and aggregate supply have been the subject of intensive investigation by central and local government in recent years. In its report published in 1976, The Advisory Committee on Aggregates (the Verney Committee), stressed the importance of rail transport of crushed rock aggregates and also mentioned the long term possibility of more underground limestone mines. Planning Control over Mineral Workings (the report of the Stevens Committee) published in 1976, contained an extensive review of the effect of planning control on mineral working and made several recommendations for changes in the legislation which are in process of implementation. Studies of reserves, production and distribution of aggregates are being carried out by a series of Local Authority Aggregates Working Parties organised on the basis of Economic Planning Regions. In addition, many county planning authorities have published reports describing mineral surveys and mineral structure plans within their respective areas. Some, for example, those for Somerset, North Yorkshire and Derbyshire include a comprehensive coverage of the local limestone industry.

THE INDUSTRY

A significant part of the limestone industry is controlled by a few major companies that own quarries distributed throughout much of the country. These include Amey Roadstone Corporation Ltd., Tarmac Roadstone Holdings Ltd., Tilcon Ltd., ECC Quarries Ltd., Steetley Minerals Ltd., and Kingston Minerals Ltd., among others. Imperial Chemical Industries Ltd., and the British Steel Corporation operate a few large quarries mainly to supply their own needs. There are also a few companies, such as Foster Yeoman Ltd. in Somerset and Staveley Lime Products Ltd. in Derbyshire, that own one or two very large quarries, the products of which are distributed over wide areas by rail. Otherwise production tends to come from local companies operating a single quarry or small group of quarries. Chalk working and building stone production in particular tends to be carried out by smaller companies.

The production of dolomite for uses other than as aggregate or in agriculture is carried out mainly by Steetley Minerals Ltd.; although Pilkington Brothers Ltd operate one quarry as a source of glass making material and Wm. Adams & Co. (Newport) Ltd. produces some industrial dolomite in South Wales.

The cement industry is dominated by Blue Circle Ltd. and the Rugby Portland Cement Co. Ltd. Smaller companies operating one or two cement plants include Tunnel Cement Ltd., Aberthaw and Bristol Channel Cement Co. Ltd., Ketton Cement Ltd. and its associate Ribblesdale Cement Ltd. (Table 6).

Production of lime is now concentrated at only a few quarries, following a decrease in the number of producers in recent years. Lime making is centred on the Carboniferous limestone, particularly in Derbyshire where it is carried out on a large scale by Imperial Chemical Industries Ltd. at Tunstead and Hindlow Quarries, by Steetley Minerals Ltd. at Dowlow Quarry and by Staveley Lime Products Ltd. at Brierlow Quarry. In Northern England lime is produced by Tilcon Ltd. at Swinden Quarry near Skipton; the British Steel Corporation has a large operation at Shap and a single kiln is operated by Sir Hedworth Williamson's Limeworks Ltd. near Kirkby Stephen. Other lime-making facilities based on Carboniferous limestone are confined to the operations of Amey Roadstone Corporation at Battscombe, Somerset, and to a kiln at Abergele, North Wales, owned by Tilcon Ltd.

Lime is made from chalk by Singleton Birch Ltd. at Melton Ross, Humberside, and by the Totternhoe Lime and Stone Co. Ltd. near Dunstable, Bedfordshire, but lime making by Blue Circle Ltd. at Rochester, Kent has now ceased.

Dolomitic lime is produced only by Steetley Minerals Ltd., from Magnesian Limestone extracted at Thrislington Quarry, Durham and Whitwell Quarry near Worksop.

In addition to the above operations, some lime is also produced as an integral part of industrial processes such as sugar refining and the ammonia soda (Solvay) process.

Although many quarries produce limestone powders for various purposes, high quality whiting is made only from domestic chalk or imported marble. Companies involved in the production of whiting from indigenous deposits include English China Clays Ltd from quarries in Humberside and Wiltshire; Blue Circle Ltd from quarries at Hull and Swanscombe, Kent; Microfine Minerals Ltd from a Humberside quarry; the Melbourne Whiting Co. Ltd from a quarry near Royston, Herts; and the Eglinton Stone Group from a quarry in Antrim.

SUBSTITUTES AND FUTURE DEMAND

Gravel, crushed limestone and other crushed rocks are natural alternatives for many coarse aggregate uses. Gravel is usually preferred as aggregate in concrete, and igneous rock or sandstone is usually necessary in road surfacing where resistance to polishing and abrasion is important. Otherwise the less porous types of limestone, which are easy to quarry and crush and form a good bond with bitumen, are extensively used as aggregate particularly in the sub-base, roadbase and basecourse of highways.

In areas where limestone is less accessible, such as Scotland or parts of Northern Ireland, igneous and metamorphic rocks substitute for many aggregate purposes. In south-east England, where gravel is becoming difficult to obtain, limestone is imported, as a substitute and as roadstone, by rail and road from Gloucestershire and Somerset. A similar situation exists in north-west England where limestone aggregate is obtained from Derbyshire, North Wales and Cumbria.

Limestone resources suitable for aggregate are so large that there is little prospect of shortages induced by exhaustion in the foreseeable future, although environmental restrictions on quarrying have raised the question of alternatives. Extensive substitution by igneous rocks might be possible but would involve massive movement of material from areas such as Northern Ireland, Scotland, Cornwall or Devon (Mineral Dossier No. 19). Sandstone substitution would involve similar problems, as suitable resources occur mainly in south Scotland, Cumbria, Wales and south-west England (Mineral Dossier No. 17). Substitution by waste material for other types of aggregate has been extensively investigated elsewhere and is commented upon in greater detail in Mineral Dossier No. 19. In general, given the decreasing output of blast furnace slag (which can be used as roadstone), the prospect for further use of waste is largely restricted to substitution for the relatively minor amount of crushed limestone used as fill.

Projection of the high growth rates in aggregate production of the 1960s, sustained largely by road construction, suggested that aggregate output might exceed 500 million tonnes a year by the turn of the century. However, in 1973 aggregate production reached 255.6 million tonnes (including 74 million tonnes of limestone), an amount which has not been exceeded since. Forecasts by the Department of Environment in March 1981 suggest that output might be in the range 185–235 million tonnes a year in the period 1984–91 but clearly much will depend on the state of the economy and in the longer term on the type of transport systems which evolve in response to energy constraints.

In the non-aggregate field, limestone and dolomite are cheap, basic raw materials for which substitution would be difficult if not impossible. Clearly the production of cement, which has declined considerably since 1973, will depend on the state of the construction industry and energy consumption per unit of cement will probably continue to decline within limits. The iron and steel industry is the next most important consumer of limestone, together with dolomite used as flux and as magnesia based refractories. Otherwise limestone and dolomite are fairly widely used and future consumption will probably depend on industrial activity generally. Agricultural demand is likely to remain relatively constant.

The future supply of limestone and dolomite for most purposes is more likely to be limited by considerations of the natural environment than by shortages of resources. For example, the IGS (Mineral Assessment Report 26) has outlined at least 3,000 million tonnes of high purity limestone (containing over 98.5% $CaCO_3$) in a relatively small area near Monyash, Derbyshire, within the Peak District National Park. Limestone and dolomite tend to form attractive countryside, which many planning authorities are reluctant to release for mineral working even in areas that are not designated National Parks or Areas of Outstanding Natural Beauty.

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Printed in England for Her Majesty's Stationery Office
by Albert Gait Ltd., Grimsby Dd. 718839 C9 2/82