Mineral Resources
Consultative Committee

Mineral Dossier No 19

Igneous & Metamorphic rock

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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

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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

Igneous and metamorphic rocks are those which have been emplaced in a molten state or substantially altered by the effects of heat and pressure.

In the United Kingdom such rocks outcrop mainly in Scotland, Northern Ireland, Wales and the South West and Northern Regions of England. Other than a few small, usually heavily exploited, outcrops in the Midlands, the remaining parts of England are devoid of resources.

Traditionally, igneous rock (including metamorphic rock) was used for building and ornamental stone, road setts, kerbs and pavements but these outlets are now minimal and the material is used preponderantly as crushed stone aggregate in road making with important minor applications as concrete aggregate and railway ballast.

In 1975 estimated consumption of crushed rock natural aggregate in Great Britain (limestone, igneous rock and sandstone) was 110M tonnes of which 32M tonnes was contributed by igneous rock. Although normally of secondary quantitative importance as a general aggregate, igneous rock becomes of primary importance in areas where other materials such as limestone or gravel are not economically available. Certain types of igneous rock (and to a lesser extent some sandstones) are of prime importance in that they provide the main natural sources of skid-resistant material available for road surfacing in the United Kingdom.

Igneous rock is often produced from quarries located in relatively small outcrops of preferred material and if these serve large markets, as is the case in Leicestershire or at some coastal sites, the quarries may be relatively large with outputs exceeding 0.5M tonnes per annum. Otherwise most important quarries tend to be of medium size with outputs in the range 0.1-0.25M tonnes per annum. The growth of the industry in recent years has led to environmental problems which are common to most aggregate producers. These include intrusion on the landscape, air and ground vibration caused by blasting, noise and dust from processing plant and difficulties in accommodating large volumes of mineral traffic on minor roads.

Geological classification

Igneous rocks are by definition formed by solidification from a molten state. They may be divided into two main groups, intrusive and extrusive. Intrusive rocks are those emplaced below the earth's surface. They usually occur as large masses or major intrusions (plutons) which have cooled slowly resulting in relatively large constituent crystals. Alternatively they may occur as minor masses such as dykes or sills which in general have cooled more rapidly resulting in medium or fine sized constituent crystals. Extrusive rocks are those formed during volcanic activity. They include lava flows and fragmentary or pyroclastic material ejected during eruptions. Lavas may be extruded on to the earth's surface or under the sea. They cool rapidly to form a fine-grained or sometimes glassy texture, occasionally with larger crystals present which formed in the lava before extrusion.

Metamorphic rocks are the result of alteration of existing igneous or sedimentary rocks by heat, pressure or chemical activity. They may be divided according to whether the alteration is primarily due to heat (thermal-metamorphism), pressure (dynamic-metamorphism), a combination of heat and pressure acting over a large area (regional-metamorphism) or chemical instability (metasomatism or autometasomatism). Thermal metamorphism is found in the heated area surrounding igneous emplacements, dynamic metamorphism occurs in highly folded or faulted areas which have been subjected to directional stress, and regional metamorphism is found where relatively large areas of the earth's crust have been subjected to conditions of high temperature and pressure.

There is very wide variation in the assemblages of minerals found in igneous rocks, which is reflected in differences in chemical composition (Tables 1 and 2). A very large number of names have been coined to describe the main types and all their varieties, which present a continuous variation in composition rather than distinct rock types. As it was recognised that a single rational and workable system for naming and classifying igneous rocks was needed, an internationally agreed system has been devised by a Commission of the International Union of Geological Sciences. However, a simpler classification, consistent with the names that appear in the trade classification included in British Standards, serves to describe the main types used for construction and other practical purposes.

Table 1 Simplified classification of major igneous rock types

	Acid	*Intermediate*	*Basic*	*Ultrabasic*
Coarse grained	Granite Adamellite Granodiorite	Syenite Diorite	Gabbro	Peridotite Picrite Pyroxenite Anorthosite
Medium grained	Microgranite Microadamellite Microgranodiorite	Microsyenite Microdiorite	Dolerite	
Fine grained	Rhyolite Dacite	Trachyte Andesite	Basalt	
Approximate $\%SiO_2$ content	>66	66–52	52–45	<45

Table 2 Typical analyses of some major igneous rock types

	Granite %	*Granodiorite* %	*Trachyte* %	*Andesite* %	*Olivine-basalt* %	*Peridotite* %
SiO_2	75.80	71.01	60.45	57.06	50.75	43.65
Al_2O_3	13.04	15.84	17.35	16.32	17.01	3.83
Fe_2O_3	0.03	0.27	2.52	4.06	9.31	2.24
FeO	1.25	1.28	1.96	1.87	0.72	8.61
MgO	0.19	0.44	1.30	3.50	2.20	33.10
CaO	0.41	2.31	2.04	8.26	7.25	3.44
Na_2O	3.20	3.97	6.84	2.41	4.20	0.64
K_2O	4.85	4.09	5.51	0.83	2.34	0.19
$H_2O > 105^oC$	0.67	0.50	0.58	3.69	1.15	2.26
$H_2O < 105^oC$	0.12	0.11	0.13	0.66	1.16	0.25
TiO_2	0.11	0.23	0.95	0.83	2.34	0.23
P_2O_5	0.18	0.05	0.48	0.29	0.78	0.06
Others	0.06	0.15	0.27	0.17	1.32	1.81
Total	99.91	100.25	100.38	99.96	100.53	100.31
Ref No.	*614*	*640*	*636*	*664*	*695*	*721*

Source: Guppy and Sabine (1956)

614 Granite: Eskdale, Cumbria
640 Granodiorite: sill in Moine Schist, Moidart, Highland
636 Trachyte: Tertiary lavas, Morvern, Highland
664 Andesite: Stoke St Michael, Somerset
695 Olivine-basalt: Lower Old Red Sandstone lava, Stonehaven, Grampian
721 Peridotite: intrusion in Lewisian Gneiss, Harris

Acid rocks

Acid rocks (Table 1), defined by their silica content, are generally light in colour and contain abundant quartz and feldspar usually with smaller amounts of mica or amphiboles. Rocks in this category are subdivided according to the composition of their constituent feldspar minerals. Feldspar in granite and rhyolite is predominantly of the sodic or potassic variety whereas feldspar in granodiorite and dacite, while being predominantly sodic, and to a lesser extent calcic, contains less potash. Adamellite occupies an intermediate position with respect to feldspar composition.

Intermediate rocks

The intermediate rocks contain little or no quartz. They are usually light in colour as feldspar is typically the dominant mineral. As with the acid rocks, subdivision is on the basis of feldspar composition. Syenites and trachytes are rich in sodic and potassic feldspar, while the feldspar in diorites and andesites contain less potash and more lime. Keratophyre is a variety of trachyte characterised by large sodic feldspar crystals set in a finer matrix.

Basic rocks

In addition to calcic feldspar, basic rocks usually contain a high proportion of ferromagnesian minerals and hence tend to be dark in colour. The major types of basic plutonic rocks are classified by their pyroxene or olivine content and also by their alkalinity. Thus if clinopyroxene predominates the rock is a gabbro, if orthopyroxene predominates it is a norite and if olivine predominates it is a troctolite.

In the medium grain sized group, dolerite is a rock of similar composition to gabbro. Epidiorite is an altered dolerite or basalt containing much hornblende.

Basalt is a very common type of volcanic lava extruded on a land or submarine surface. It may also occur in minor intrusions. Spilites are altered sodic basalts, in places characterised by a pillow structure resulting from extrusion underwater. Diabase is the obsolescent term for an altered dolerite or basalt containing such minerals as chlorite and calcite.

Rocks with a high alkali and low silica content form a separate class of basic rocks which have a complicated nomenclature. However these are uncommon and have little economic importance in the United Kingdom.

Ultrabasic rocks

Ultrabasic rocks are also relatively rare and of little commercial importance in the United Kingdom. Those which occur are intrusive and tend to consist essentially of one or two minerals. Pyroxenites are composed mainly of pyroxene, peridotites are rich in olivine and picrites contain olivine and pyroxene with a little feldspar. Anorthosites are composed entirely of calcic feldspar.

Other important igneous rock types used in trade descriptions but not covered in the above classification are described below.

Aplites and pegmatites

Pegmatites are extremely coarse grained rocks, frequently of granitic composition, when they tend to have a varied content of minor minerals which are rich in such fluxes as boron, fluorine and lithium, and may also contain such heavy metals as tin, tungsten and tantalum. Aplites are a fine grained equivalent of granitic pegmatites.

Granophyres and felsites

These are acidic rocks generally occurring in minor intrusions. Felsites are usually pink and consist mainly of fine grained quartz and feldspar. Granophyres have a characteristic 'graphic' texture resulting from intergrowths of quartz and orthoclase.

Porphyries

Porphyries usually occur as minor intrusions. The rock is characterised by the presence of large crystals or phenocrysts set in a finer groundmass of quartz, feldspar etc. Porphyrite is a porphyritic rock composed of sodic feldspar with hornblende or biotite and sometimes quartz. Basic porphyrite is richer in ferromagnesian minerals but contains no quartz.

Lamprophyres

Lamprophyres are particularly rich in well shaped ferromagnesian minerals such as biotite and hornblende.

Serpentinite

Serpentinite is a rock consisting essentially of the mineral serpentine, which has been formed by the alteration of olivine in ultrabasic or gabbroic rocks.

Pyroclastic rocks

The term pyroclastic is applied to rocks which have originated as fragments ejected from a volcano. Accumulations of large angular fragments are known as 'agglomerates' while those composed of smaller fragments are called volcanic breccias. Fine volcanic ash, often forming a matrix for lapilli or volcanic bombs, when consolidated is known as tuff. Ash deposited in water can form a type of sedimentary deposit and particularly if mixed with detrital material can give rise to such hybrid rock types as tuffaceous sandstones.

The classification of metamorphic rocks, unlike igneous rocks, is too complex to be expressed in simple tabular form or to be described fully in a dossier. Some of the more abundant and economically important metamorphic rocks are described below. A more comprehensive coverage of the subject is given by Harrison and Sabine (1970).

Thermally metamorphosed rocks

Thermal or contact metamorphism normally occurs when sedimentary rocks have been affected by the intrusion of a nearby mass of hot igneous rock. At high temperature, shales, mudstones and greywackes become baked, and hard alumino-silicate minerals are formed. Rocks having suffered this type of alteration are known as hornfels on account of their horny or flint-like aspect. In quartzites and quartzitic sandstones which have been thermally metamorphosed, all amorphous silica is converted to quartz and the rock becomes non-porous.

Dynamic and regionally metamorphosed rocks

The effect of heat and pressure gives rise to a series of alterations which commonly affect large areas and a wide variety of rock types. Pressure usually imparts to a rock some form of foliation which is related to the direction of original stress, and where there is local pressure-induced movement the rock may become highly sheared.

Where rocks are more intensely metamorphosed, pressure and temperature effects tend to become less distinct, although minerals continue to recrystallize in such a way that new crystal orientation is related to the original stress direction. With extreme pressure and temperature conditions the less refractory constituents of a rock begin to melt until, eventually, the whole rock can become mobilized and may be intruded in the form of an igneous body.

Slate is formed by the action of directed pressure on clay-rich sediments. It is characterised by the presence of regular, close-spaced cleavage-planes which are perpendicular to the direction of the greatest pressure which has acted on the rock. In certain circumstances fine grained lustrous rocks known as *phyllites*, and characterised by their content of the white micaceous mineral sericite, are formed. Higher temperatures and more intense forces acting on clayey sediments lead to the formation of schists. The constituent minerals, particularly micas or amphiboles tend to be orientated with their short axes parallel to the major stress direction so that planes of easy splitting occur; usually the schistose texture is less regular than the cleavage in a slate and may have a wave-like profile. Various schists are distinguished by means of the characteristic mineral name used as a prefix, for example *biotite-schists* and *garnet-mica* schists.

Gneisses are formed from both sedimentary and igneous rocks, by metamorphic conditions more intense than those which give rise to schists. They are characterized by a coarse grain size and a pronounced banded structure, determined partly by differences in original composition and accentuated by segregation occurring under the extreme pressure and temperature conditions. Gneisses are classified on the basis of their characteristic mineral, eg cordierite-gneiss or garnet-gneiss. A granulite, or granulose gneiss, consists of interlocking granular minerals such as feldspar, pyroxene and garnet of about equal grain size. Extreme metamorphism, resulting in partial melting, gives rise to gneissic rock structures formed partly by magmatic flow and partly by pressure. Such thoroughly mixed and reconstituted types are known as composite gneiss or migmatite. They represent a final stage of metamorphism beyond which more intense conditions would result in complete melting.

Limestone or dolomite when subjected to heat or pressure recrystallize to marble. However, when impurities such as silica or alumina are present, these react to form a variety of rock types depending on mineral assemblages which are stable within the thermodynamic limits of the system. A common example involves the formation of forsterite in marble containing magnesia and silica.

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 and placed in one of the following groups, Artificial, Gritstone, Basalt, Hornfels, Flint, Limestone, Gabbro, Porphyry, Granite, Quartzite, Schist.

All except the Artificial and Flint groups contain igneous or metamorphic rock types. Examples of rock types within each relevant group together with their geological classification are given in Table 3.

Table 3 Geological classification of rock types in BS 812 : 1975

Groups	*Primary geological classification*		
	Sedimentary	*Igneous*	*Metamorphic*
Gritstone	conglomerate, arkose greywacke, grit, sandstone, breccia	agglomerate, tuff, breccia (volcanic)	
Basalt		andesite, basalt, basic porphyrites, diabase, dolerite, lamprophyre, quartz-dolerite, spilite	hornblende schist, epidiorite
Hornfels			contact altered rocks of all types except marble

Table 3 (Contd.)

Groups	*Primary geological classification*		
	Sedimentary	*Igneous*	*Metamorphic*
Limestone	dolomite, limestone		marble
Gabbro		basic diorite, gabbro, hornblende-rock, norite, peridotite, picrite, serpentine	basic gneiss
Porphyry		aplite, dacite, felsite, granophyre, keratophyre, micrograníte, porphyry, quartz-porphyrite, rhyolite, trachyte	
Granite		granite, granodiorite, pegmatite, gneiss, granulite, quartz-diorite, syenite	
Quartzite	ganister quartzitic sandstone		re-crystallized quartzite
Schist			phyllite, schist, slate, all severely sheared rock

Although the above grouping is somewhat inconsistent with respect to usual geological classifications, in that some groups contain both sedimentary and volcanic, or sedimentary and metamorphic, rocks, it forms a useful practical basis for commercial transactions and has done much to reduce the confusion which formerly existed over rock names used in quarrying.

In practice however, some confusion over nomenclature still remains particularly with respect to the term *granite* which tends to be greatly misused. For example, so-called Ingleton 'Granite' is a greywacke, and several of the greywackes and gritstones produced in Mid-Wales are referred to as 'granites'. The term *whinstone* is also used loosely. It is applied to dolerite and basalt but occasionally incorrectly to greywacke or other dark compact rock. The term 'grey whinstone' is sometimes used to describe metamorphic rock. Many metamorphic rocks have similar properties to igneous rocks and in commercial usage the term *igneous* rock often includes metamorphic rock.

The confusion in terms is also occasionally reflected in official statistics, the main effect being that production of some sedimentary rocks tends to be returned in the igneous category.

Although they are metamorphic rocks, slate and quartzite used for refractory or chemical purposes are dealt with in detail in Mineral Dossiers Nos. 12 and 18. Other quartzites are grouped with sandstones in Mineral Dossier No. 17.

Mechanical properties

For engineering purposes, igneous and metamorphic rocks, like other materials, are classified according to the mechanical properties relating to their end use.

For use as aggregate or building stone, probably the most important property of a rock is its shear strength or resistance to crushing. Where the rock is used in block form, as in building or paving stone, strength is determined by testing single small blocks to the point of failure and expressing the result as a pressure. With coarse aggregates test procedures have been developed by the Transport and Road Research Laboratory. Strength testing consists of subjecting a closely-sized sample of aggregate to known crushing forces in a standard container for a fixed time. The result is expressed as the percentage of material which has been reduced to below a given size, and 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 ten per cent of the weight of the sample is reduced to below a standard particle size. This quantity, known as the 10 per cent fines value is measured as a force (KN) and was introduced because ACV measurements tend to be unreliable in weaker rocks. Although a more time-consuming measurement, it can be applied universally with confidence.

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 co-efficient of friction in percentage terms.

Resistance to surface abrasion of aggregates 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 then the Aggregate Abrasion Value (AAV).

Other physical properties of practical importance include water absorption and porosity, which are useful in assessing the 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 per cent fines values are a measure of the shear strength of the material by a method which should exclude many of the anisotropic effects of structural weaknesses such as bedding planes or joints. However there may be other weaknesses resulting from incipient fractures caused by the crushing process used to produce the aggregate. The AIV, a measure of a combination of impact resistance and shear strength, has a similar numerical value to the ACV (for many materials). However, in glassy, or other highly stressed, materials which shatter on impact a relatively high AIV can be expected. 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 and on the ease with which particles are abraded from the surface. In consequence, high PSV tends to be associated with low abrasion resistance and therefore with low strength. Hence there is difficulty in finding rocks with a combination of high strength and high PSV suitable for road surfacing.

Examples of the mechanical properties for various rock types are given below under 'Industry'.

Uses and specifications

Igneous and metamorphic rocks were at one time of prime importance as sources of building stone, road setts, pavement and monumental stone. However, exploitation is now devoted overwhelmingly to the production of aggregate for use mainly in roadmaking, and for such important applications as concrete aggregate and railway ballast (Table 4). Some types of igneous rock are of widespread importance in that, together with some sandstone, they provide the only raw materials with the necessary skid resistance properties required for road surfacing. Crushed igneous rock is also used for various types of fill, for specialist uses such as filter media, dressings for tennis courts etc. Large blocks are used for protection against erosion of dams and coastal works.

There is a very minor outlet for some types of igneous rock after remelting to produce such materials as rock wool or cast basalt.

Table 4 End uses of igneous rock produced in Great Britain in 1975

	Thousand tonnes	*%*
Building stone	18	0.1
Coated roadstone	7,250	22.2
Uncoated roadstone	10,515	32.2
Railway ballast	2,307	7.1
Concrete aggregate	3,659	11.2
Other construction purposes	8,593	26.3
Other purposes	303	0.9
Total	32,645	100.0

Roadstone

Coarse aggregate used in highway construction is called roadstone. The structure of a typical flexible main road is shown in Fig 1. The sub-base consists of unbound or lightly bound aggregate, which distributes the load on to the subsoil (the sub grade) so as to raise the bearing capacity above a minimum level; the roadbase is the main load-bearing layer of the foundation; the basecourse forms the main element in the surfacing, which is overlain by a thin wearing course to provide the texture of the road surface. Specifications for materials used in road making are given in *Specification for Road and Bridge Works* by the Department of Transport and in British Standards and some County highway authorities' specifications.

For most major highways,'Type 1 Granular Sub-base Material' is specified, which allows for the use of crushed rock with a size range mainly between 37.5 mm and 5.0 mm. Material finer than 4.25 mm is required to be non-plastic and aggregate to be used within 0.45 m of the road surface must be frost resistant. This requirement excludes the more porous types of stone.

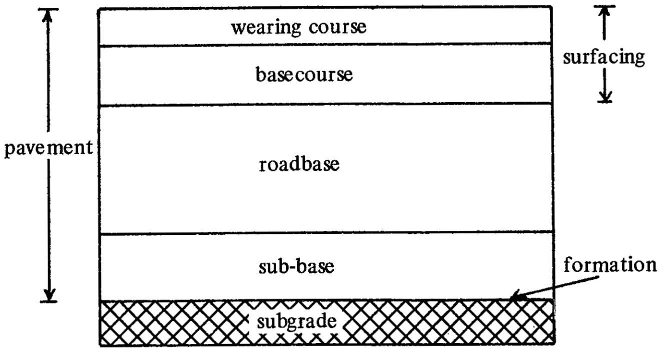

Fig 1 Cross-section of a typical highway.

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. 'Wet Mix' and 'Dry' Macadams, both uncoated materials similar to, although somewhat finer than, those used for 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 specification for the aggregate are similar to those used for coated roadbase materials, except that for Dense Bitumen Macadam the size distribution of the coarse aggregate is specified as a function of the compacted thickness of the basecourse.

The wearing course provides a regular shaped riding surface which will withstand the direct tractive forces and loads from traffic, protect the underlying layers from the elements and provide 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 per cent coarse aggregate, with coated chippings rolled into the surface, is used most frequently.

The requirement for aggregate properties in surfacing of new motorways and trunk roads is rigorously specified to match skid resistance with various highway layouts and traffic flows. Minimum PSV and maximum AAV requirements are specified for dry or coated chippings applied to the running surface and to bituminous or tar bonded coarse aggregates in wearing coarses, basecourses and roadbases, where these are used to provide a non-dressed running surface. These requirements are given in the following tables.

Table 5 Minimum Polished Stone Values for materials used in highway running surfaces

Site (see notes below)	*Approximate percentage of roads in England*	*Traffic density in number of commercial vehicles per lane per day*	*Minimum PSV*
A1	0.1	250	60
(difficult)		250-1,000	65
		1,000-1,750	70
		1,750	75
A2	4.0	1,750	60
(difficult)		1,750-2,500	65
		2,500-3,250	70
		3,250	75
B	15	1,750	55
(average)		1,750-4,000	60
		4,000	65
C	85	–	45
(easy)			

A1 sites include:

i. Approaches to traffic signals on roads with 85 per centile speed of traffic greater than 64 km/h.

ii. Approaches to traffic signals, pedestrian crossings and similar hazards on main roads.

A2 sites include:

i. Approaches to and across major priority junctions on roads carrying more than 250 commercial vehicles per day.

ii. Roundabouts and their approaches.

iii. Bends with radius less than 150 m on roads with an 85 per centile speed of traffic greater than 64 km/h.

iv. Gradients of 5 per cent or steeper, longer than 100 m.

B sites include generally straight sections of and large radius curves on:

i. Motorways.

ii. Trunk and principal roads.

iii. Other roads carrying more than 250 commercial vehicles per lane per day.

C sites include:

i. Generally straight sections of roads carrying less than 250 commercial vehicles per lane per day.

ii. Other roads where wet skidding accidents are unlikely to be a problem.

NB The PSV of coarse aggregate in rolled asphalt and dense tar surfacing, having coated chippings applied to the surface, should not be less than 45 for sites in categories A1, A2 and B. There is no limit for sites in category C.

Table 6 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.

Concrete aggregate

Concrete is usually made from a mixture of cement and aggregate in the approximate ratio 1:5. Fine and coarse aggregates are used either separately or as a combined 'all-in' aggregate.

The aggregates should be hard (the lower strength limit is generally specified), durable and clean and should not contain any deleterious material which might adversely affect the strength of the concrete, its durability, or its resistance to frost and corrosion. 'Deleterious material' includes clay, particularly as an adherent coating, flaky and elongated particles, mica, shale and other laminated materials, coal and other organic impurities, iron pyrites and soluble sulphates (BS 882 : 1973). The shrinkage of the aggregate must not be excessive, the aggregate must not be susceptible to frost damage and it must not be subject to attack by the alkaline cement environment.

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

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 the strength of the final concrete by a factor of two to four and it does not necessarily follow that stronger aggregates produce stronger concrete. Generally crushed rock aggregates consist of angular particles which result in a concrete of lower workability but higher strength compared with a similar mix made from gravel. Thus it has been shown that crushed rock aggregates are essential for the production of very high strength concrete and that the flexural strength of crushed rock concretes are higher than gravel concretes. The mixes require a similar cement content irrespective of the type of aggregate used.

Traditionally, high strength materials such as dolerite have been preferred for railway ballast, the main requirement being for material with high resistance to impact and attrition sufficient to absorb the hammering effect of rail traffic without degradation of the ballast.

Building stone and other uses

Stone with relatively low compressive strength can be used for building although in practice most building stones have greater strength than is required. Resistance to shattering by the action of frost and crystallization of soluble salts is perhaps the most important property, which depends largely on the size and extent of voids in the stone and is usually expressed as the Ratio of Porosity to Water Absorption. Stone with low porosity, or with large pores which allow absorbed water to drain out quickly, tends to have good lasting properties, whereas a stone with a high proportion of fine pores will be susceptible to damage.

In the United Kingdom, the building stone producers working igneous rocks are no longer suppliers of basic building material in their localities. Rather they supply a national, and occasionally international, specialist market strongly influenced by aesthetic factors. Hence the choice of igneous rock for building stone tends to be strongly dependent on such factors as colour and crystal texture. In some areas reconstituted stone blocks, made from concrete with igneous rock aggregate, are used in place of traditional building stone.

Rock wool similar in application to glass fibre, is a fibrous, heat-insulating material, made by the melting and extrusion of suitable rock. The manufacturing process consists essentially of allowing the molten rock to be drawn through a fine orifice under the action of inclined steam jets. The lime-rich mixture used previously (eg dolomite and fireclay or dolerite and limestone) has now been replaced by an olivine basalt feed. Although this material has a higher melting point, it produces fibres with an improved performance at high temperatures which can compete more effectively with asbestos for some purposes. At present production is confined to two plants which consume a very small proportion of the total igneous rock production.

Remelted basalt cast into special linings for steel pipes is sometimes used in coal washeries and other plant carrying abrasive solids where protection against excessive wear is required. Approximately 3,000 tonnes of this material is used in the United Kingdom annually, all of which is imported in finished form from West Germany or Czechoslovakia. The melting and casting plant is somewhat specialised as melt temperatures in excess of 1200^{o}c are required. In addition cooling after casting requires careful control over a 24 hour period to produce a devitrified strain free material consistent with maximum strength and durability.

Production statistics

Since 1895, when official production statistics were first collected, just over 1,000 million tonnes of igneous rock have been produced in the United Kingdom. Annual production increased from approximately 5 million tonnes in the early years of the century to about 15 million tonnes in 1959, after which it increased sharply to reach a peak of 46.6 million tonnes in 1973. Since 1965, nearly 40 per cent of the total recorded output of igneous rocks has been produced reflecting the high demand for aggregate in recent years, although there has been a marked decrease in output since 1973.

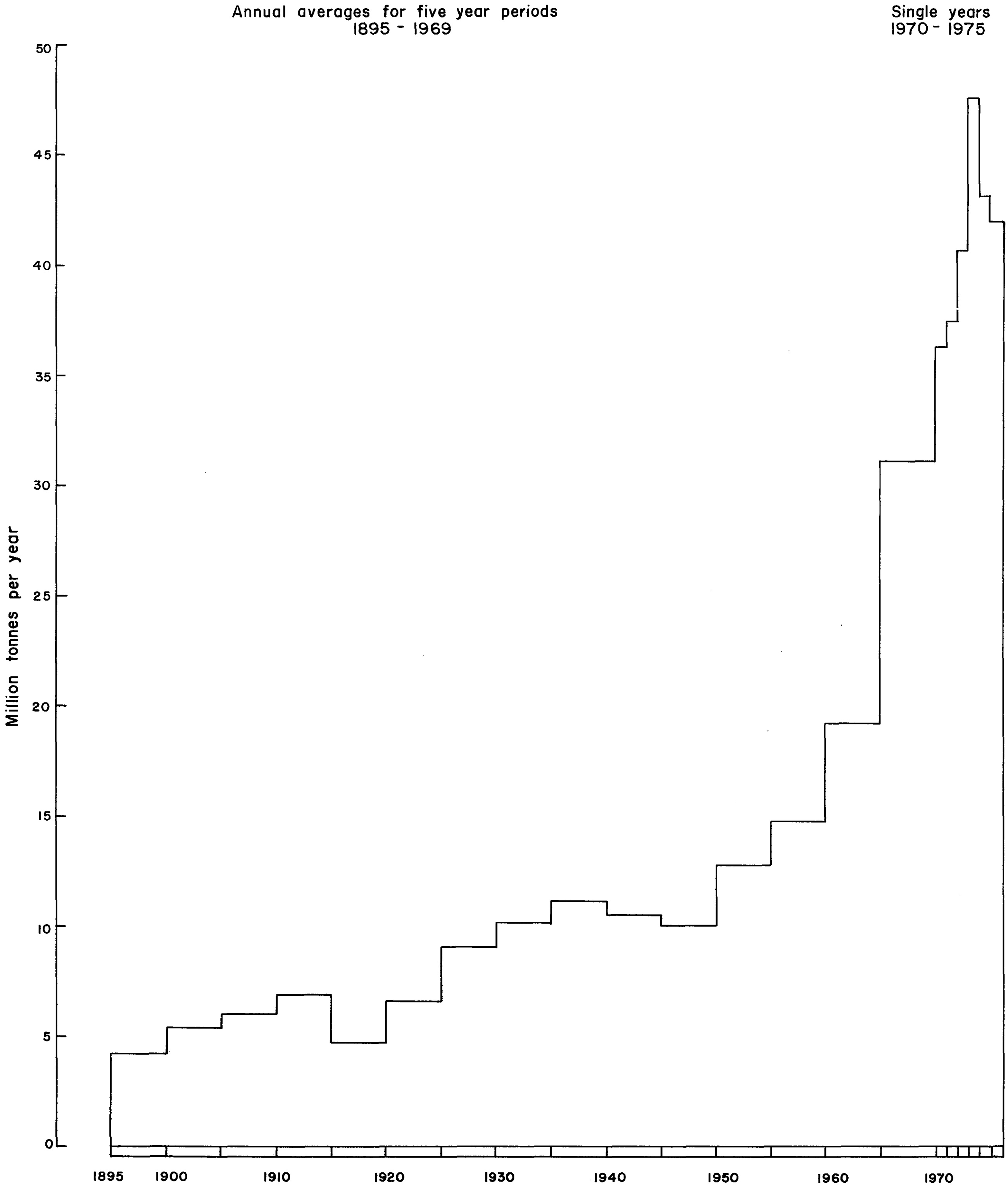

Fig 2 United Kingdom production of igneous and metamorphic rock 1895-1975.

Production since 1895 is shown in Table 7 and Fig 2. The old distribution of county production in England from 1967 to 1972 is shown in Table 8 and corresponding data on a new county basis for 1973 and 1974 is given in Table 9. Data for Scotland presented on an old county basis, for the period 1967-74, is given in Table 10 and corresponding data on a regional basis for 1975 is given in Table 11. Data for Wales is given in Tables 12 and 13. In many cases county outputs are grouped together to preserve confidentiality of returns by individual producers.

A study of the geographical distribution of igneous rock production emphasises the importance of Scotland and Northern Ireland which, in 1975, contributed 35 per cent and 22 per cent of output respectively. In England, Leicestershire leads other counties in the output of igneous rock with approximately 14 per cent of United Kingdom production in 1975. Cornwall, Devon, Northumberland, Warwickshire and West Midlands are also important producing areas.

Table 14 shows the end uses of igneous rocks extracted in various parts of Great Britain. The relative importance of roadstone is notable in comparison with the very small quantities going for building stone. It is estimated that in 1975 some 30 per cent of the crushed rock aggregates produced in Great Britain was contributed by igneous rock, 61 per cent by limestone and 9 per cent by sandstone.

Table 7 United Kingdom. Production of igneous rock 1895-1974

5 year period	*Total production*			*Annual average*
	Great Britain (b)	*Northern Ireland (a)*	*United Kingdom*	*United Kingdom*
		Million tonnes		
1895-1899	20.3	0.6	20.9	4.2
1900-1904	25.9	0.8	26.7	5.3
1905-1909	29.2	0.9	30.1	6.0
1910-1914	32.4	1.5	33.9	6.8
1915-1919	22.2	1.2	23.4	4.9
1920-1924	31.3	1.6	32.9	6.6
1925-1929	42.8	2.4	45.2	9.0
1930-1934	48.0	2.4	50.4	10.1
1935-1939	53.0	2.4	55.4	11.1
1940-1944	46.5	6.1	52.6	10.5
1945-1949	45.3	3.9	49.2	10.0
1950-1954	58.1	5.4	63.5	12.7
1955-1959	67.1	6.5	73.6	14.7
1960-1964	83.1	12.2	95.3	19.1
1965-1969	120.7	37.3	158.0	31.6
1970-1974	161.0	42.4	203.4	40.7
1975	32.6	9.4	42.0	–
Total	919.5	137.0	1,056.4	

(a) 1914-18 estimated from returns including Irish Republic
(b) Includes Isle of Man

Table 8 United Kingdom. Production of igneous rock 1967-72 with breakdown by old counties in England

Thousand tonnes

County and Country	*1967*	*1968*	*1969*	*1970*	*1971*	*1972*
Northumberland	937	1,019	1,087	1,309	1,579	1,562
Durham	461	515				
Cumberland						
Westmorland			1,253	1,073	930	852
Yorkshire	755	748				
Lancashire	—	—	—	—	—	—
Derby	1,511	1,533	1,482	1,518	1,646	1,706
Shropshire						
Hereford, Worcester	259	272	1,541	6,247	1,812	2,302
Stafford	1,178	1,257				
Warwick	4,126	439	4,766			
Leicester		4,074			4,982	5,541
Devon	982	1,002	834	759	1,571	1,629
Somerset	370	1,882	1,911	2,082		
Cornwall	1,418				1,586	1,923
Total England	11,997	12,741	12,874	12,988	14,106	15,515
Wales	2,295	2,531	2,630	2,722	2,618	2,548
Scotland	10,502	11,324	12,016	12,279	12,503	13,916
Total Great Britain	24,974	26,596	27,520	27,989	29,227	31,979
Northern Ireland	9,427	7,482	8,286	8,119	8,100	8,608
United Kingdom	34,221	34,078	35,806	36,108	37,327	40,587

Source: Department of the Environment

Table 9 United Kingdom. Production of igneous rock 1973-74 with breakdown by new counties in England

Thousand tonnes

County and country	*1973*	*1974*	*1975*
Cumbria, Durham, Cleveland	2,062	516	696
Northumberland		1,695	1,750
Derby, Leicester	6,463	5,829	5,940
Lancashire		—	—
Cornwall	2,332	2,296	2,275
Devon, Somerset	1,869	1,804	1,538
Hereford, Worcester, Salop	1,951	1,403	1,138
Warwick, West Midlands	3,033	2,850	2,883
Total England	17,710	16,388	16,221
Wales	2,443	2,512	1,837
Scotland	18,164	15,989	14,588
Total Great Britain	38,317	34,889	32,646
Northern Ireland	9,308	8,195	9,371
United Kingdom	47,625	43,084	42,017

Source: Business Statistics Office

Table 10 Scotland. Production of igneous rock 1967-74 with breakdown by old counties

Thousand tonnes

<table>
<tr><th>County</th><th>1967</th><th>1968</th><th>1969</th><th>1970</th><th>1971</th><th>1972</th><th>1973</th><th>1974</th></tr>
<tr><td>Sutherland</td><td>–</td><td rowspan="2">293</td><td rowspan="2">253</td><td rowspan="2">440</td><td rowspan="2">316</td><td rowspan="2">628</td><td rowspan="2">430</td><td>–</td></tr>
<tr><td>Shetland, Ross and Cromarty</td><td>283</td><td>805</td></tr>
<tr><td>Inverness</td><td>316</td><td>363</td><td>326</td><td>300</td><td>369</td><td>375</td><td>607</td><td>593</td></tr>
<tr><td>Nairn</td><td rowspan="2">316</td><td rowspan="2">378</td><td rowspan="2">367</td><td rowspan="2">375</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Moray, Banff</td><td rowspan="2">983</td><td rowspan="2">1,188</td><td>389</td><td>419</td></tr>
<tr><td>Aberdeen</td><td>519</td><td>513</td><td rowspan="2">1,363</td><td rowspan="2">1,260</td><td>1,284</td><td>1,670</td></tr>
<tr><td>Angus</td><td rowspan="2">703</td><td rowspan="2">787</td><td rowspan="3">1,013</td><td rowspan="3">1,083</td><td>890</td><td>754</td></tr>
<tr><td>Kincardine</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Perth, Clackmannan</td><td>230</td><td>219</td><td rowspan="2">558</td><td rowspan="2">517</td><td>425</td><td>458</td></tr>
<tr><td>Argyll</td><td>339</td><td>357</td><td>332</td><td>372</td><td>381</td><td>343</td></tr>
<tr><td>Stirling</td><td>361</td><td>309</td><td>590</td><td>803</td><td>969</td><td>854</td><td>1,457</td><td>946</td></tr>
<tr><td>Fife</td><td rowspan="2">1,028</td><td rowspan="2">1,076</td><td rowspan="2">1,212</td><td rowspan="2">1,540</td><td rowspan="2">1,385</td><td rowspan="2">1,402</td><td>2,242</td><td>1,298</td></tr>
<tr><td>Kinross</td><td>–</td><td>–</td></tr>
<tr><td>Dumbarton</td><td>740</td><td>785</td><td>1,042</td><td rowspan="2">1,810</td><td rowspan="2">1,815</td><td rowspan="2">2,048</td><td>915</td><td>1,144</td></tr>
<tr><td>Renfrew</td><td>1,083</td><td>1,038</td><td>975</td><td>1,543</td><td>1,632</td></tr>
<tr><td>Lanark</td><td>1,260</td><td>1,363</td><td>1,256</td><td>1,159</td><td>1,174</td><td>1,266</td><td>1,910</td><td>1,044</td></tr>
<tr><td>Midlothian</td><td>909</td><td>1,118</td><td rowspan="3">1,445</td><td rowspan="3">1,369</td><td rowspan="2">1,341</td><td rowspan="2">1,584</td><td rowspan="2">1,786</td><td>1,073</td></tr>
<tr><td>East Lothian</td><td rowspan="2">234</td><td rowspan="2">243</td><td rowspan="2">353</td></tr>
<tr><td>West Lothian</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Roxburgh</td><td>140</td><td>86</td><td rowspan="2">542</td><td rowspan="2">463</td><td rowspan="2">441</td><td rowspan="2">615</td><td rowspan="2">1,232</td><td rowspan="2">584</td></tr>
<tr><td>Peebles, Berwick</td><td>339</td><td>326</td></tr>
<tr><td>Bute</td><td rowspan="2">1,151</td><td rowspan="2">1,475</td><td>–</td><td>. . .</td><td>–</td><td>–</td><td>. . .</td><td>. . .</td></tr>
<tr><td>Ayr</td><td rowspan="2">1,743</td><td rowspan="2">1,868</td><td rowspan="2">2,027</td><td rowspan="2">2,104</td><td rowspan="2">2,267</td><td rowspan="2">2,488</td></tr>
<tr><td>Kirkcudbright</td><td rowspan="2">287</td><td rowspan="2">308</td></tr>
<tr><td>Wigtown</td><td rowspan="2">344</td><td rowspan="3">375</td><td rowspan="2">338</td><td rowspan="2">397</td><td rowspan="3">406</td><td rowspan="3">385</td></tr>
<tr><td>Dumfries</td><td>264</td><td>287</td></tr>
<tr><td>Bute</td><td>. . .</td><td>. . .</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Total Scotland</td><td>10,502</td><td>11,324</td><td>12,016</td><td>12,279</td><td>12,502</td><td>13,916</td><td>18,164</td><td>15,989</td></tr>
</table>

Source: Department of Environment and Business Statistics Office

Table 11 Scotland. Production of igneous rock 1975 with breakdown by Regions

Region	*Thousand tonnes* *1975*
Borders, Dumfries and Galloway	788
Central	956
Fife	1,195
Grampian	2,076
Highland, Shetland, Western Isles	1,143
Lothian	1,349
Strathclyde	6,128
Tayside	954
Total	14,588

Source: Business Statistics Office

Table 12 Wales. Production of igneous rock by old counties 1967-72

Thousand tonnes

County	*1967*	*1968*	*1969*	*1970*	*1971*	*1972*
Anglesey	224	250	259	1,242	806	831
Caernarvon	580	676	939			
Denbigh					343	509
Merioneth	685	714				
Montgomery			1,432	1,480	1,469	1,208
Radnor, Carmarthen, Pembroke	806	891				
Brecon	–	–	–	–	–	–
Total	2,295	2,531	2,630	2,722	2,618	2,548

Source: Department of Environment

Table 13 Wales. Production of igneous rock by new counties 1973-75

Thousand tonnes

County	*1973*	*1974*	*1975*
Clwyd	–	1,048	–
Gwynedd	1,039		1,039
Dyfed	1,404	529	797
Powys		934	
Total	2,443	2,512	1,837

Source: Business Statistics Office

Table 14 Production of igneous rock in Great Britain in 1975 by end-uses

Tonnes

England	*Roadstone*		*Railway ballast*	*Concrete aggregate*	*Other construc-tional uses*	*Other purposes*	*Total*
	Coated	*Uncoated*					
Cumbria, Durham, Cleveland	139,868	215,843	65,000	71,558	203,230	463	695,962
Northumberland	571,841	491,458	126,934	319,221	240,976	–	1,750,430
Derby, Leicester	1,131,572	1,999,818	865,094	691,653	1,252,330	–	5,940,467
Cornwall	573,979	807,550	–	471,643	410,955	10,956	2,275,083
Devon, Somerset	307,828	470,838	220,731	112,158	395,660	30,871	1,538,086
Hereford and Worcester, Salop	442,032	206,965	1,752	43,897	443,292	–	1,137,938
Warwick, West Midlands	845,518	535,823	343,466	140,638	1,017,258	–	2,882,703
Total	4,012,638	4,728,295	1,622,977	1,850,768	3,963,701	42,290	16,220,669
Wales							
Gwynedd	209,964	285,678	} 148,214	215,991	160,865	} 39,707	1,039,160
Dyfed, Powys	236,415	183,148		152,051	204,489		797,362
Total	446,379	468,826	148,214	368,042	365,354	39,707	1,836,522
Scotland							
Borders, Dumfries and Galloway	141,950	311,377	–	123,648	210,734	20	787,729
Central	316,635	309,053	78,470	126,040	94,163	31,658	956,019
Fife	210,085	379,792	146,779	50,956	353,830	54,036	1,195,478
Grampian	462,447	918,687	–	115,700	554,901	24,090	2,075,825
Highland, Shetland, Western Isles	245,093	257,011	54,906	188,554	359,955	37,170	1,142,689
Lothian	226,993	424,015	10,983	267,483	419,255	–	1,348,729
Strathclyde	923,707	2,277,142	216,878	562,156	2,060,704	87,519	6,128,106
Tayside	264,522	441,028	27,429	5,621	210,042	5,195	953,837
Total	2,791,432	5,318,105	535,445	1,440,158	4,263,584	239,688	14,588,412
Great Britain	7,250,449	10,515,226	2,306,636	3,658,968	8,592,639	321,685	32,645,603

* Includes building stone: Great Britain total – 18,147 tonnes

Source: Business Statistics Office

Overseas trade

The most recent data on overseas trade include returns of unworked building and monumental stone, that is crude, roughly split or sawn stone, in which granite is distinguished from other types of igneous rock. For worked stone the exports and imports are included under different groupings which makes for some difficulty in comparison. Igneous rock aggregates are included in a residual category together with other types of crushed rock (Table 15).

Table 15 United Kingdom imports and exports of building and monumental stone, pebbles, gravel and crushed stone including igneous rock, 1976

		Imports		*Exports*	
		Quantity tonnes	*Value £ cif*	*Quantity tonnes*	*Value £ fob*
Building and monumental stone					
A Unworked					
	Granite	11,868	835,000	1,291	28,000
	Porphyry and basalt	34	2,000	–	–
	Others	474	27,000	249	23,000
B Worked					
	Granite (imports only)	3,926	847,000	*na*	*na*
	Granite flagstone (exports only)	*na*	*na*	57	3,000
	Other worked stone (exports only)	*na*	*na*	966	321,000
Aggregates					
	Pebbles, gravel, flint and shingle	83,380	100,000	4,446,242	304,800
	Macadam etc	–	–	4,067	38,000
	Others (including uncoated igneous rock)	66,070	295,000	148,107	376,000
	Total aggregates	149,450	395,000	4,598,416	3,462,000

na Not available

Source: HM Customs and Excise

The main Brussel Trade Nomenclature (BTN) headings under which igneous rock is recorded are shown below:

BTN heading and description		*Remarks*
25.16	Granite, porphyry, basalt sandstone and other monumental building stone including such stone not further worked than roughly split, roughly squared or squared by sawing.	Granite is recorded separately in a number of different codings, both sawn and unsawn and of various shapes and sizes. Other rocks listed are similarly recorded. (Calcareous stone, alabaster and slate are included separately under other BTN headings).
68.01	Road and paving setts kerbs, and flagstones of natural stone.	Granite flagstones are separately distinguished.
68.02	Worked monumental or building stone and articles thereof (including mosaic cubes) other than goods falling within 68.01.	Granite in various forms is separately recorded, as are articles etc of calcareous stone and alabaster, and some flint. All other igneous rock and other stone is included in residual headings. Export descriptions do not separately record granite except as flagstone (Table 12).

Prior to 1976 trade in igneous monumental and building stone other than granite was not recorded and trade in aggregates was included together with pebbles, gravel, macadam etc. Consequently, it is impossible to derive any statements regarding the trade in igneous rock as a whole for previous years. Such data as is available for the years 1971-75 is given in Tables 16 and 17 and a breakdown of granite used for building and monumental purposes by country of destination and consignment is given in Tables 18 and 19.

Table 16 United Kingdom imports of granite for use as building and monumental stone and stone for aggregate 1971-76

	1971	*1972*	*1973*	*1974*	*1975*	*1976*
Unworked granite (*tonnes*)	12,705	15,711	13,673	18,845	14,677	11,868
value *£ cif*	353,091	437,786	456,630	683,371	811,288	835,000
Worked monumental or building stone and other articles in granite (*tonnes*)	3,401	4,629	5,687	4,491	6,484	3,926
value £ cif	334,939	394,658	613,886	567,211	1,217,199	842,000
Pebbles, crushed and broken stone (*tonnes*)	103,392	113,042	153,322	157,730	345,705	149,450
value *£ cif*	224,264	328,118	384,338	434,627	872,222	395,000

Source: HM Customs and Excise

Table 17 United Kingdom exports of granite and some other stone for use as building and monumental stone and stone for aggregate 1971-76

	1971	*1972*	*1973*	*1974*	*1975*	*1976*
Unworked granite *(tonnes)*	131	87	104	1,639	890	1,291
value £ *fob*	9,496	5,169	3,902	41,415	25,718	28,000
Worked granite as flagstones *(tonnes)*	152	34	23	150	15	57
value £ *fob*	3,601	570	641	12,000	1,746	3,000
Other worked stone *(tonnes)*	640	678	1,004	1,581	7,410	966
value £ *fob*	108,889	93,139	164,740	198,596	289,466	321,000
Pebbles crushed and broken stone *(tonnes)*	3,864,780	3,837,125	4,095,476	4,768,519	4,091,001	4,598,416
value £ *fob*	2,025,312	2,159,297	2,342,729	2,538,088	2,689,732	34,620,000

Source: HM Customs and Excise

Table 18 United Kingdom imports of granite 1973-75

	1973		*1974*		*1975*	
Country of Consignment	*Tonnes*	*£ cif*	*Tonnes*	*£ cif*	*Tonnes*	*£ cif*
Unworked granite						
S Africa	5,351	157,327	3,005	119,710	5,162	247,107
Sweden	3,917	166,771	4,484	210,327	4,296	289,511
Portugal	1,869	23,674	484	10,868	446	11,600
Finland	1,160	34,434	2,645	92,537	2,139	84,779
USA	714	30,541	942	52,128	1,270	78,175
Norway	355	12,144	2,285	72,765	125	11,980
Irish Republic	15	185	3,474	13,863	110	9,569
France	–	–	100	3,804	626	31,700
Italy	162	27,125	367	59,908	191	31,989
India	91	2,629	–	–	66	3,272
Saudi Arabia	–	–	135	7,477	108	4,035
Mozambique	–	–	508	20,893	–	–
Other countries	39	1,800	416	19,091	138	7,571
Total	13,673	456,630	18,845	683,371	14,677	811,288
Worked granite						
India	2,415	203,672	2,252	240,471	3,206	389,436
S Africa	780	135,954	495	112,786	728	189,046
Portugal	704	23,642	475	22,876	504	14,405
Finland	434	33,947	115	14,830	74	20,913
Italy	399	92,657	309	48,208	1,131	344,211
Sweden	315	33,434	148	25,040	110	49,633
Poland	247	29,758	205	35,222	229	46,306
Norway	152	6,883	5	200	46	15,279
Irish Republic	87	22,094	27	4,907	98	28,908
USA	47	12,651	159	44,925	325	108,833
Germany Fed Rep	42	4,294	1	2,938	1	4,344
Belgium - Luxembourg	21	5,724	220	2,784	–	–
Other countries	44	9,176	80	12,024	32	5,885
Total	5,687	613,886	4,491	567,211	6,484	1,217,199

Note: Owing to changes in classification the data is not strictly comparable throughout the period.

Source: HM Customs and Excise

Table 19 United Kingdom exports of granite 1973-75

	1973		*1974*		*1975*	
Country of Destination	*Tonnes*	*£ fob*	*Tonnes*	*£ fob*	*Tonnes*	*£ fob*
Unworked granite						
Belgium-Luxembourg	–	–	1,306	18,352	711	12,500
Italy	–	–	160	13,012	65	5,858
Irish Republic	41	1,538	55	3,022	53	1,923
Egypt	–	–	–	–	38	4,404
France	0	50	–	–	18	655
Netherlands	–	–	18	350	2	120
USA	–	–	9	3,255	–	–
Canada	15	789	–	–	–	–
Gibraltar	–	–	50	450	–	–
Abu Dhabi	–	–	33	2,177	–	–
Denmark	48	1,525	–	–	–	–
Other countries	–	–	8	797	3	258
Total	104	3,902	1,639	41,415	890	25,718
Worked stone (including granite flagstones)						
Germany Fed Rep	25	1,499	62	23,124	5,446	25,946
Nigeria	17	2,903	15	2,568	473	3,195
Iran	48	6,591	80	13,233	333	37,603
France	78	11,982	117	11,519	252	21,219
Irish Republic	250	18,853	232	26,092	146	30,694
Italy	2	323	8	1,754	115	4,779
Canada	82	10,495	34	6,889	114	29,908
USA	108	54,098	509	44,096	86	25,139
Sweden	1	55	–	–	63	4,562
Finland	7	631	–	–	59	8,089
Spain	–	–	2	355	45	16,879
Netherlands	7	2,557	–	–	43	10,926
Venezuela	38	5,303	–	–	40	10,386
Australia	51	4,077	267	23,542	6	2,543
Saudi Arabia	117	14,786	–	–	5	1,393
Other countries	196	31,228	405	57,424	199	57,951
Total	1,027	165,381	1,731	210,596	7,425	291,212

Note: Owing to changes in classification the data is not strictly comparable throughout the period.

Source: HM Customs and Excise

Resources

Igneous and metamorphic rocks are unevenly distributed in the United Kingdom: for example, all rocks outcropping in south-east England and East Anglia are sedimentary and there are only relatively small outcrops of igneous rocks in the Midlands. Igneous and metamorphic rocks become extensive only in SW England, parts of Wales, parts of northern England, Scotland and Northern Ireland.

Resources of different rock types are described below.

Granites and other acidic plutonic rocks

Granites are particularly abundant in South West England, where there are five large masses, Dartmoor, Bodmin Moor, St. Austell, Carnmenellis and Lands End, ranging from 10 to 30 km in diameter, together with several smaller outcrops, one of which forms the Scilly Isles. Granite is also important in the Channel Islands.

The igneous rocks of Leicestershire include a number of intermediate intrusions together with a granodiorite at Mountsorrel which, in an area where hard rock is rare, have considerable economic importance.

In North Wales there are several relatively small granite intrusions, the larger of which include the Coedana granite in the Precambrian of Anglesey and the Twt Hill granite near Bangor. Other small granites of Ordovician age include the Llanbedrog and Sarn granites of the Lleyn peninsula, in addition to which there are many minor intrusions described as microgranites, porphyries or felsites. In south-west Wales, there are some small Precambrian granites near St. Davids and Haycastle.

In northern England there is a large mass of granite in Eskdale and a granophyre in Ennerdale. Other smaller intrusions include the granites of Shap and Skiddaw, together with the St. Johns and Threlkeld microgranites. The Isle of Man, which is geologically similar to the Lake District, has small granite intrusions at Foxdale and Laxey. The Cheviot Hills igneous complex consists of the deeply eroded remains of a volcano intruded by a roughly circular granite mass some 50 sq km in area.

In southern Scotland there are three major granites of Devonian age, at Cairnsmore of Fleet, Loch Doon and Criffell, all about 8 to 16 km in diameter, together with several smaller masses such as those at Cairnsmore of Carsphairn and Afton Water. In the Scottish Highlands, granite masses are larger and more abundant than in any other part of the United Kingdom but because of their remoteness from industrial centres many of them are of little economic importance. The majority of the Highlands granites are of Devonian or Caledonian age and belong to a group known as the *Newer Granites,* because they were intruded after the main metamorphism of the region. Granites of this type include the great masses of Cairngorm, Lochnagar, Hill of Fare, Moor of Rannoch, Loch Etive and Strontian (Fig 3) which individually range in area up to 500 sq km. The so-called *Older Granites* are rocks which have been subjected to intense metamorphic processes, becoming folded and gneissic. They are often associated with migmatites. Tertiary granites and related acidic rocks occur at various centres of igneous activity in the Western Highlands and Islands (Fig 4). The main granites in this group comprise the northern granite in Arran which is about 18 km in diameter and a granite of comparable size in the Red Hills, Skye. There is a smaller granite in central Arran, but in other Tertiary centres such as Ardnamurchan, Mull, Rhum and St. Kilda, the acidic rocks are granophyres rather than granites.

In Northern Ireland the Caledonian Newry Granite outcrops over an area of some 400 sq km in Counties Down and Armagh and corresponds to the Newer Granites of Scotland in that it is fresh and unfoliated. Smaller Caledonian granites in Co. Tyrone include some migmatite, while the small Cushendun granite in Co. Antrim is of Newer type.

A Tertiary granite, similar to those found in Western Scotland, underlies the Mourne Mountains, and is exposed over an area of 150 sq km in Co. Down. Tertiary granophyres occur in the Slieve Gullion complex, in south Armagh, interbedded with dolerites.

Basic and ultrabasic plutonic rocks

In England basic plutonic rocks are relatively rare. They are confined to a group of serpentinites and gabbros occurring in association with metamorphic rock in the Lizard peninsula and to a complex suite of igneous rocks at Carrock Fell in the Lake District consisting mainly of gabbro cropping out over an area of about 10 sq km. In the Isle of Man there is an intrusion of gabbroic rocks at Oatland and gabbro is of economic significance in the Channel Islands.

The Ballantrae Igneous complex in the South of Scotland is comprised of serpentinite in association with ultrabasic rock types and gabbro. Two norite masses are associated with the southern and north western ends of the Loch Doon granite.

North-west of Aberdeen there is a group of exceptionally large basic intrusives, one of which, the Insch mass, exceeds 180 sq km in area and includes peridotite, troctolite, olivine-norite and hypersthene-gabbro. The other bodies include similar rock types. In many localities, the original basic magma has reacted with adjacent sedimentary rocks giving rise to unusual hybrid types such as norites containing cordierite and garnet.

Elsewhere in the Highlands there are numerous smaller plutonic complexes which are basic in parts such as occur at Glen Doll and Garabal Hill. In addition there are innumerable small igneous bosses some of which are basic or ultrabasic.

The Tertiary volcanic centres in the Western Highlands and Islands frequently contain basic plutonic rocks. In Skye, the Cuillin range is largely composed of gabbro with small amounts of ultrabasic rock while in the neighbouring island of Rhum there is a large gabbroic intrusion together with a great development of ultrabasic rock. Other basic intrusions are present in Ardnamurchan and Mull and to a lesser extent in central Arran and on St. Kilda (Fig 4).

In Northern Ireland there are small gabbroic intrusions associated with the Central Tyrone igneous complex and the Newry granite complex has basic parts, particularly at Slieve Croob where differentiation into peridotite, pyroxenite and intermediate types has occurred. Of the intrusions associated with Irish Tertiary centres, only the Carlingford complex, which is in the Republic of Ireland, contains much gabbro. Centres such as Slieve Gullion and the Mourne Mountains contain only dolerite or acidic rock types.

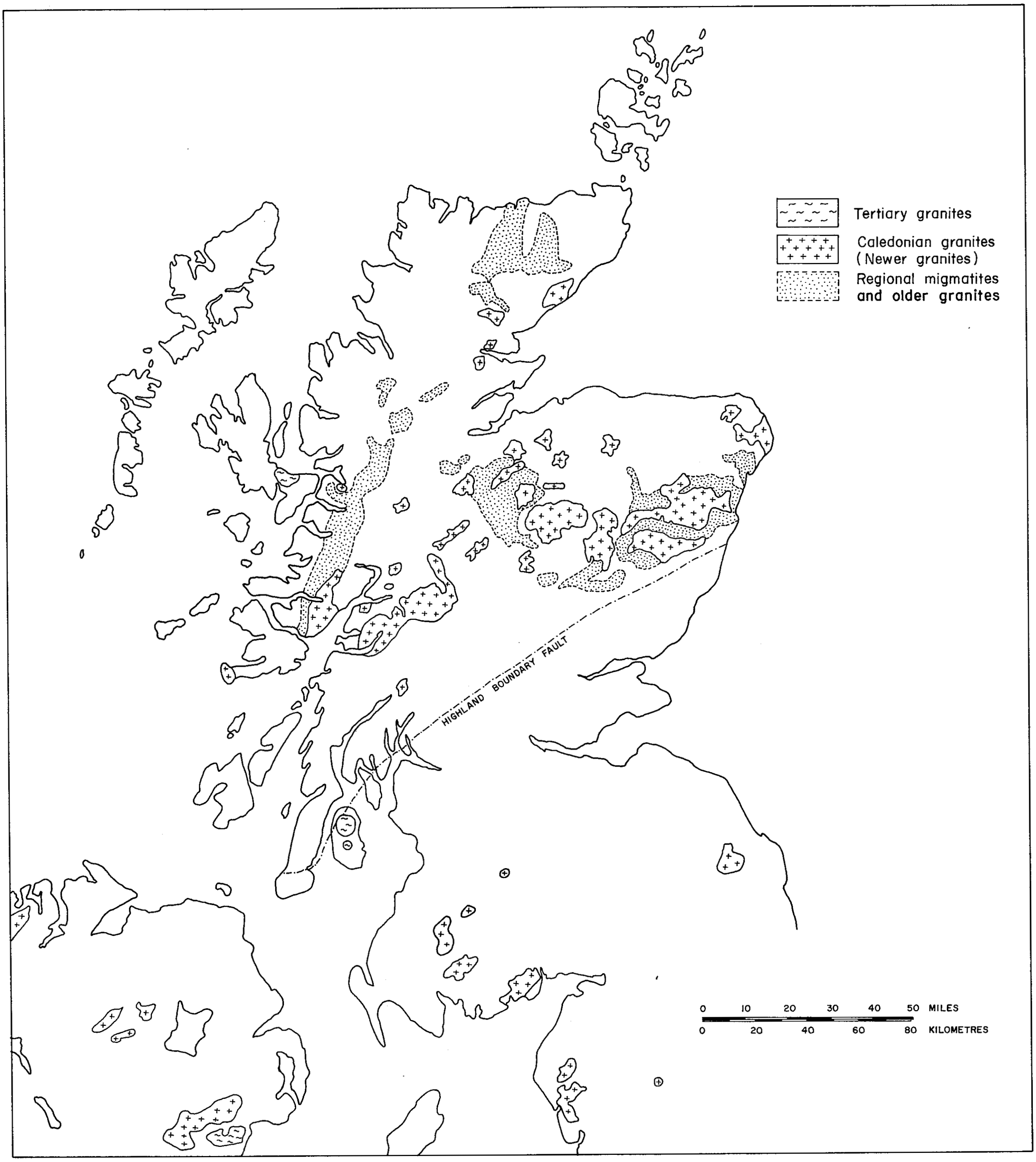

Fig 3 Major granite outcrops in Scotland, Northern Ireland and northern England.

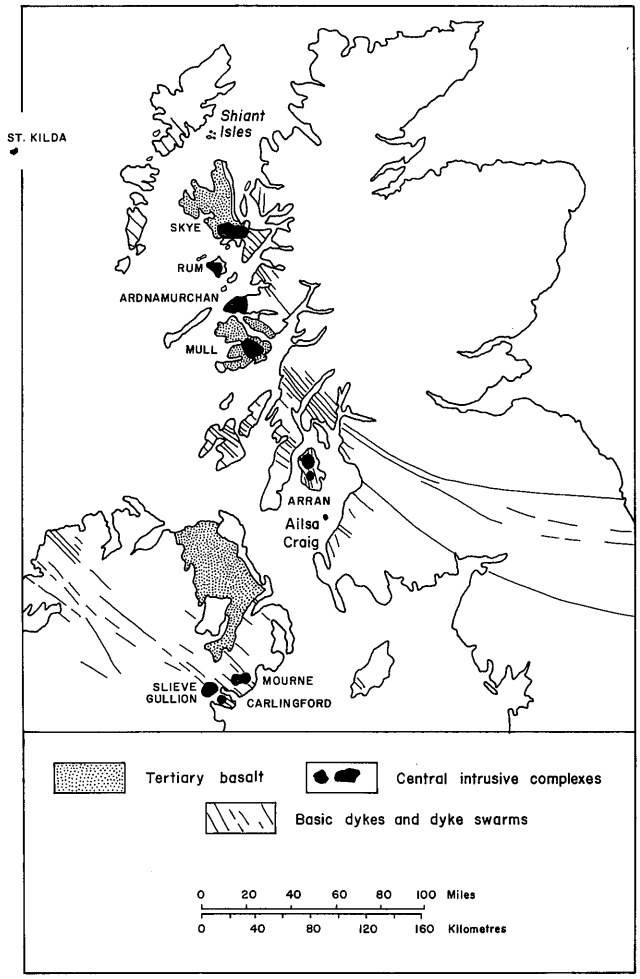

Fig 4 Distribution of Tertiary plutonic centres with associated basalt lava flows and north-west trending dykes.

Intermediate plutonic rocks and minor intrusions of acidic and intermediate composition

In Leicestershire, in addition to the Mountsorrel granodiorite noted above, there are several small intrusions of intermediate composition which are of considerable economic importance. These include the diorites of the Newhurst, Markfield, Enderby, Bradgate, Lawnwood, Groby and associated intrusions, and, further south, the quartz diorites of Croft, Narborough and Sapcote.

In south-east Wales, several Precambrian intrusions include quartz porphyry, diorite and granophyre. In the Ordovician of Ramsey Island there are sills of quartz-albite porphyry. Numerous small Ordovician intrusions known variously as porphyrites, felsites or microgranites are important in North Wales and include the intrusions of Penmaenmawr and Nevin among many others.

In the Lake District there are some small intrusions of intermediate composition, including the so-called Embledon granite which is in fact a diorite, between Cockermouth and Bassenthwaite. In the Crossfell Inlier and the Howgill Falls there are several acid porphyries and lamprophyres.

In the south of Scotland there are many small granodiorite intrusions such as Priestlaw, Cockburn Law and Stonehill Hill. Also diorite and granodiorite form mantles around some of the granites, particularly the Loch Doon mass, and there are other diorites associated with the Portencorkrie and Glen Luce intrusions. Predominantly NE-SW trending diorite and lamprophyre dykes are also quite common throughout much of the southern uplands.

In the Old Red Sandstone of the Midland Valley there are diorite masses in the Distinkhorn, Tincarn and Fore Burn complexes, and in the Ochil and Pentland Hills. Porphyrite minor intrusions are present around the Distinkhorn complex and near Dalmellington, Garleften Fell and Maybole.

In the Highlands, for example at Comrie, Glen Doll, Glen Tilt, Glen Falloch, Reay and Ratagan, there are several igneous complexes contemporaneous with the Newer Granites showing a variety of basic to acidic rock types which include diorite.

Groups of minor intrusions described in some places as *Hybrids of Ach'uaine type* are scattered throughout the Highlands; they vary from basic to acidic composition and include diorite and other intermediate rock types. Around Loch Loyal there are relatively large masses of syenite, associated with minor syenite intrusions in the surrounding country rock.

In Northern Ireland there is a diorite intrusion associated with the Newry granite but otherwise intermediate rocks are insignificant.

Basalts, dolerites and associated rock types

The oldest rocks in this category in South West England consist of basalts and dolerites of the Lizard complex. Altered basalts and dolerites, known as greenstones, are widely distributed in Devon and Cornwall where they are associated with Devonian and Carboniferous sediments as lavas and intrusions. They are commonly associated with pillow lavas and form prominent coastal headlands such as those at St. Ives and Botallack. The outcrops, being related to sheet-like flows or sills are frequently long and narrow, and occasionally are repeated by folding.

Numerous sill-like dolerite intrusions, examples of which form the promontories of St. David's Head and Strumble Head, are emplaced in the Lower and Middle Ordovician sediments of Pembrokeshire. Similar intrusions are also present in an Ordovician inlier at Builth Wells although some of these appear to take the form of plug-like intrusions rather than conventional sills. In North Wales there are a great number of doleritic intrusions in Ordovician rocks, particularly in the area around Dolgellau, in Snowdonia and to a lesser extent in the Berwyn Hills.

In the Precambrian of Shropshire, dolerite and basalt occur in Uriconian rocks which crop out in the Wrekin and Pontesford areas. Cambrian rocks in the Nuneaton, Wrekin, Pontesford and Malvern districts contain minor intrusions of basic rocks which were probably emplaced in Ordovician times. Similarly Ordovician rocks which outcrop in the Stiperstone, Shelve and Chirbury areas contain basic intrusives, the larger masses among them having resulted in the formation of Carndon Hill and Breidden Hill.

Basalts and dolerites occur in association with Coal Measures at several localities in the Midlands but mainly within a narrow belt extending from the Clee Hills in the west to the Leicestershire Coalfield in the east. This includes the igneous rocks of Clee Hills, Kinlet, Shatterford and various outcrops in the Black Country, particularly around Rowley Regis, Wednesfield and Walsall. In Derbyshire dolerite and basalt occur as vent infillings, lavas and sills associated with Lower Carboniferous rocks.

In the Lake District, basalt lava flows occur in the Borrowdale Volcanic Series although these are generally subsidiary to intermediate lavas. There are also dolerite intrusions, examples of which include Castle Head and Friars Crag, Keswick, together with a dolerite complex at Haweswater. The Manx Slates in the Isle of Man contain several basic 'greenstone' dykes composed mainly of dolerite or lamprophyre, which have been subjected to shearing stresses and dragged out into disconnected lenticular masses of crushed material.

Intrusive rocks and some volcanics are associated with Carboniferous strata in northern England. The volcanics include the Cockermouth lavas of West Cumberland and the Scarlet Volcanic Group in the Isle of Man. Among the intrusive rocks, the Whin Sill is a most important resource which crops out at intervals from near Bamburgh and Alnwick on the Northumberland coast to the Tyne Valley, near Haltwistle, along the Pennine escarpment and in Teesdale. The sill averages some 25 to 30 m in thickness, reaching a maximum of 73 m underground in Weardale. Four major east-north-east trending dyke-echelons which are related to the Whin Sill include the dykes of Holy Island, Lewisburn-High Green, St. Oswalds Chapel and Hett.

In the south of Scotland, other than the dolerites and spilites of the Ballantrae complex and the spilitic lavas associated with Ordovician sediments, basic volcanic rocks and minor intrusions tend to occur within the Carboniferous. Numerous flows of basaltic lava were deposited over the whole area north-eastwards from the Solway Firth to near the East coast. In the south-west they are called the Birrenswark Lavas and further to the north-east the local name is Kelso Traps. The Border Region also contains numerous small volcanic necks which tend to form prominent topographic features. These are mainly filled with basalt, basaltic agglomerate or more acidic rock types.

Occurrences of basic lava flows and associated minor intrusions are so common in the Midland Valley that only a superficial description of their outcrops is possible (Figs 5 and 6). The oldest volcanics occur in the Lower Old Red Sandstone which crops out on both sides of the Midland Valley and although most are andesitic, basalts occur fairly commonly. Much of the Carboniferous and Permian were periods of intense local volcanic activity, resulting in extensive eruptions of basaltic lavas, such as the Clyde Plateau Lavas, with numerous basaltic volcanic necks and associated sills and dykes. The Midland Valley Quartz-Dolerite Sill complex which crops out on both sides of the Firth of Forth is the most extensive of the sills and of considerable economic importance. Other sills of similar age but of more alkaline composition occur.

Around some of the Tertiary volcanic centres are extensive tracts of basaltic lavas (Fig 4), together with arcuate dolerite intrusions known as cone sheets which are particularly abundant around the Ardnamurchan and Mull centres. Swarms of dolerite dykes, each dyke about 2 to 3 m thick, are often associated with the centres. In one traverse of 20 km near the Mull centre, some 375 separate dykes have been recorded with an aggregate thickness of 770 m. Most of the dykes trend north-west to south-east and a few extend through southern Scotland into northern England.

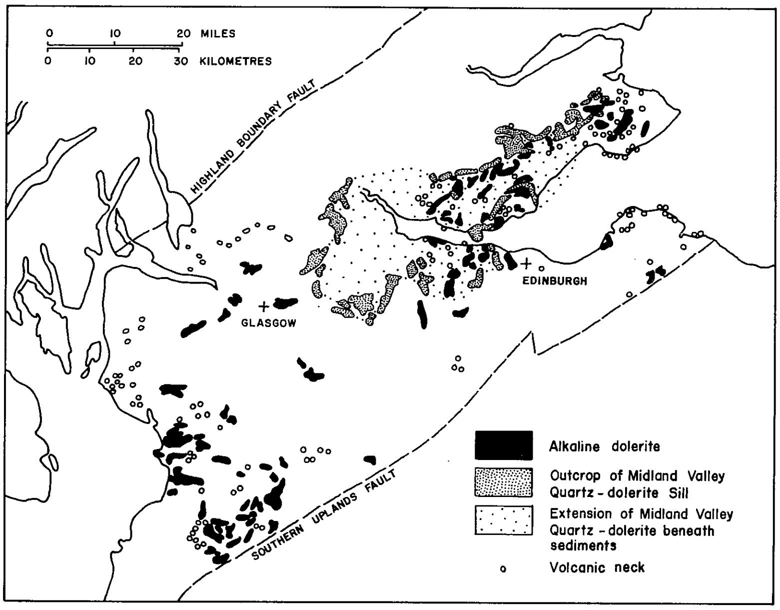

Fig 5 Distribution of alkaline dolerite Sills, volcanic necks and Midland Valley Quartz – dolerite Sill in Central Scotland.

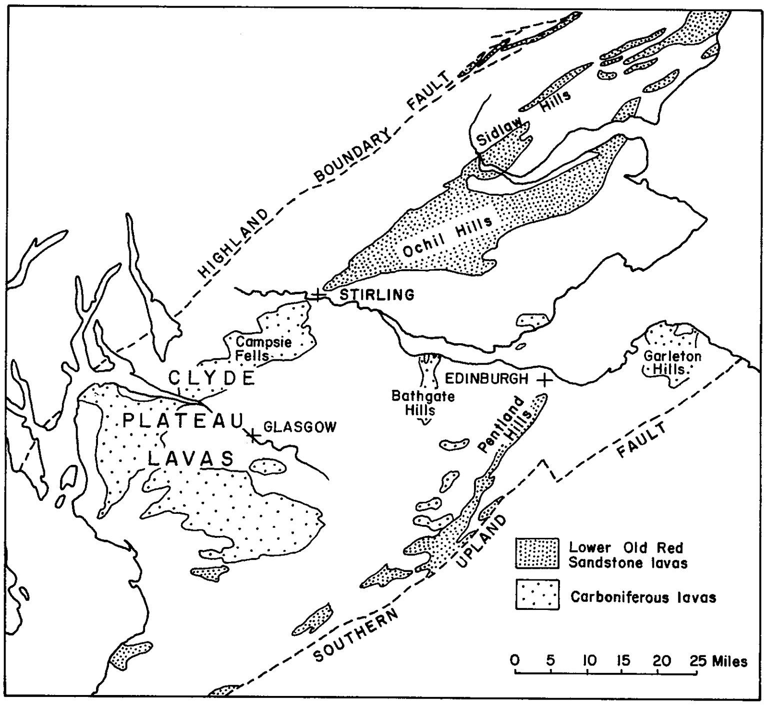

Fig 6 Distribution of lavas in Central Scotland.

In Northern Ireland, Tertiary volcanic activity produced vast outpourings of basalt which now form the Antrim plateau. This area is the largest single basalt outcrop in the British Isles and accounts for most of the basalt production in the United Kingdom. Minor basic intrusions connected with Tertiary activity occur frequently and magma-filled pipes are known at over thirty localities within the Antrim plateau where they tend to form raised prominences standing above the surrounding basalt. There are also a number of large sills intruded into sedimentary rocks adjacent to the lava plateau. Dykes are common and tend to focus on the plutonic centres, otherwise they have a preferred north-west to south-east trend similar to that of the Tertiary dykes in Scotland.

Andesites, rhyolites and associated acidic and intermediate lavas

Lavas and tuffs of acidic and intermediate type are found in Uriconian rocks which crop out in western Shropshire and the Malvern Hills.

In Leicestershire, the Charnian rocks contain various acid and intermediate lavas and tend to be particularly rich in pyroclastic material. The alteration of the original lavas due to low grade metamorphism has tended to increase their strength to beyond that normally associated with volcanic material, thus enhancing their economic potential as a source of aggregate.

Ordovician rocks, which crop out extensively in Wales, are particularly rich in andesitic and rhyolitic volcanics, for example in the Snowdon range and the semi-circular area around the Harlech Dome including the mountains of Arenig Fawr, Rhobell Fawr, and Cader Idris. Outcrops of similar material are frequent in a zone extending from the Lleyn Peninsular to Conway. In south-west Wales acidic volcanic rocks are well developed in the islands and the mainland adjacent to St. Brides Bay. A relatively small outcrop of andesite in the Mendips is worked.

In the Lake District and the Cross Fell Inlier the Ordovician Borrowdale Volcanics comprise a great thickness of mainly andesitic and rhyolitic lavas, tuffs and agglomerates. The Ordovician rocks of the Southern Uplands in Scotland also contain andesitic volcanics. The Cheviots are made up of andesites of Devonian age and andesitic and acidic lavas are very common in the Lower Old Red Sandstone which crops out over considerable areas on both sides of the Midland Valley of Scotland.

Carboniferous extrusive material in the Midland Valley is largely dominated by basaltic rock types but includes some trachyte, trachyandesite and rhyolite lavas. There are also occasional volcanic necks filled with trachytic agglomerate. Further north, in the Grampian Highlands, Lower Old Red Sandstone volcanics form the Lorne Plateau between Loch Awe and Oban and occur in other small areas in Glen Coe and on Ben Nevis.

In Northern Ireland the Ordovician volcanic series of mid-Tyrone contains andesitic tuffs and the Old Red Sandstone in Tyrone and Antrim contains andesite lava flows and minor intrusions. There is an extensive Tertiary rhyolite dome, and associated rhyolite lavas, at Tardree, Co. Antrim, in the middle of the basaltic Antrim Lava Group.

Metamorphic rocks

Thermal metamorphism in the proximity of igneous rocks varies greatly in character, intensity and extent depending upon the original temperature, depth of emplacement and mass of the igneous body. On the other hand, areas of regionally metamorphosed rock are much more extensive.

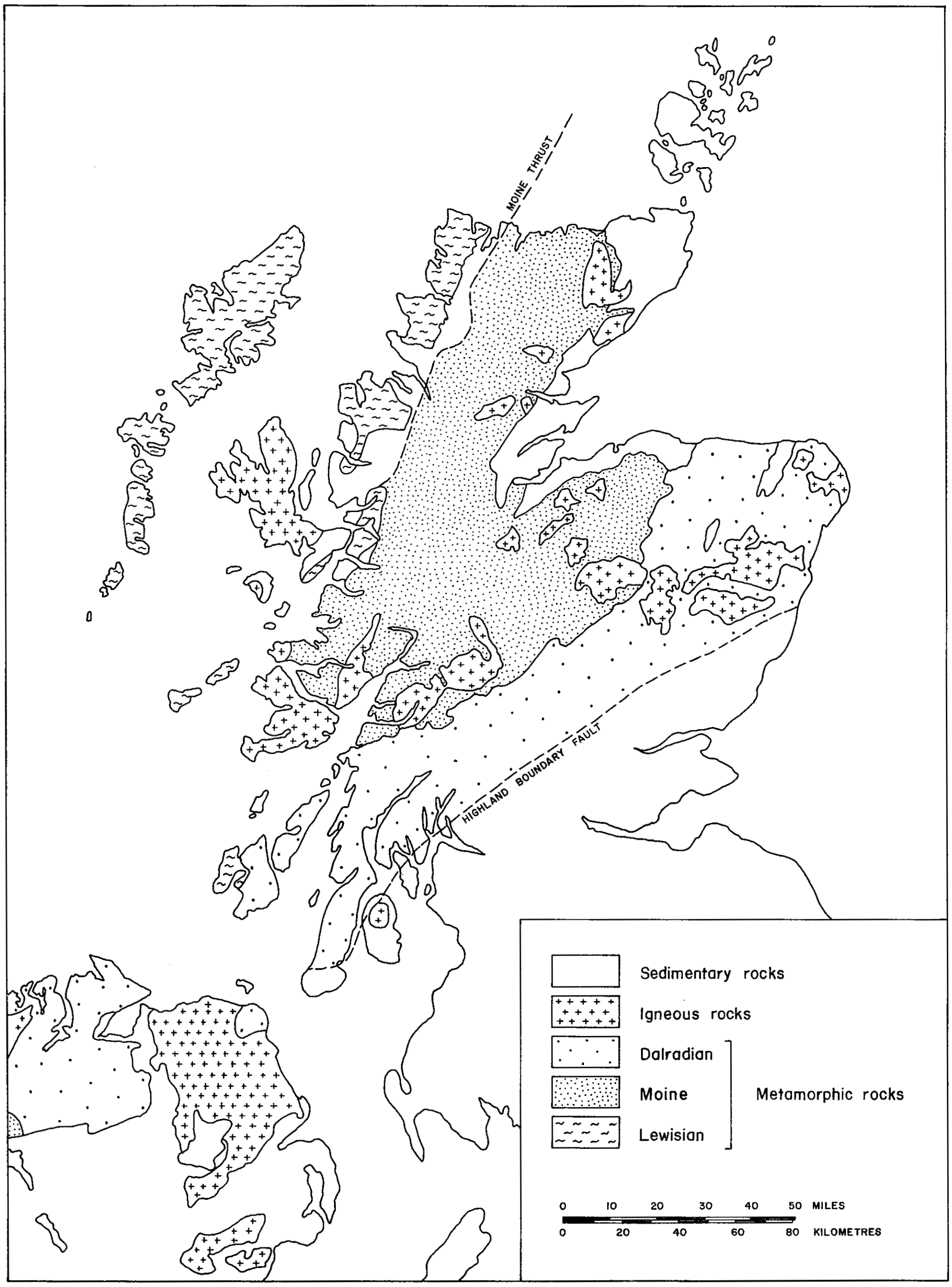

Fig 7 Simplified geological map showing the major metamorphic rocks of Scotland and Northern Ireland.

The oldest metamorphic rocks in Scotland comprise the Precambrian Lewisian gneiss which crops out extensively in the north-west and in the Hebrides, particularly in the outer islands. Frequently overlain by Torridonian 'Sandstone', it is found in a wide belt extending along the north-west coast from near Kyle of Lochalsh to Cape Wrath, and further inland, in numerous inliers surrounded by Moine rocks. The Lewisian is highly metamorphosed and consists for the most part of gneissic rocks varying in composition from acid to basic, and, less commonly, crystalline limestones and quartzites (Fig 7). Most of the north-west Highlands and northern Grampians are composed of the Moine succession of metamorphosed sediments, consisting mainly of granulites and mica schists, together with igneous rocks intruded prior to metamorphism and migmatites formed by the remelting of existing rock. In the southern part of the Grampians, Moine rocks give way to the Dalradian series of mainly metamorphosed Cambrian sediments which include a wide variety of rock types, such as quartzites, schistose grits, limestones, calc-silicate rocks, slates, phyllites and schists.

Both Moine and Dalradian rocks have been subjected to non-uniform regional metamorphism which has resulted in the formation of a series of zones each characterised by distinct mineral assemblages controlled by the original rock composition and the pressure and temperature conditions to which it has been subjected. Migmatites are found where conditions were most intense and are surrounded by roughly concentric zones of successively less metamorphosed rocks.

Dalradian and to a lesser extent Moine rocks similar to those found in Scotland are present in Northern Ireland. The Dalradian occupies an area of some 2,500 sq km in western Londonderry, Tyrone and north Fermanagh; in addition there is a small isolated outcrop in north-east Antrim. Moine rocks, known as the Lough Derg Psammites, are present in western Fermanagh and extend into the adjacent part of Donegal. There are other smaller areas of metamorphic rocks including an igneous and metamorphic complex in Central Tyrone.

The Precambrian rocks of Anglesey and Lleyn contain a group of gneisses and a group of bedded highly-folded sedimentary rocks in which recrystallised quartzites are of importance. In the Welsh Borders, the Malvern Hills include a group of Precambrian gneisses and schists, and similar rocks occur in a small outcrop at Primrose Hill near the Wrekin. A quartz mica schist, the Rushton schist, also occurs near Rushton to the east of the Wrekin.

In the Midlands, the Precambrian rocks of Charnwood Forest in Leicestershire comprise an intensely cleaved series of sedimentary and volcanic rocks.

The industry

The location of igneous rock quarries is determined largely by economic factors which tend to be dominated by the cost of haulage. Hence quarries are sited on those outcrops which are well placed to serve the main markets by road or, to a lesser extent, by rail or coastal shipping.

The production cost of igneous rock aggregate is higher than that of crushed limestone or gravel because the abrasiveness of igneous rock causes considerable wear to crushing plant. Consequently in areas where they are abundant, crushed limestone or gravel are usually used in preference to igneous rock in concrete or the lower levels of road pavements. However, for highway surfacing, only some igneous rocks (and occasionally some sandstones) can meet the required abrasion and polish resistance specifications. Because of this there has been a need to exploit igneous rocks primarily for surfacing, although once a quarry is established the product is not usually used exclusively for this purpose. Only in areas short of gravel or limestone is there any marked tendency to use igneous rock for general purposes. These factors may be modified locally by variations in markets, changes in transport costs and the details of individual construction schemes, but in general they apply throughout the United Kingdom.

An approximate breakdown of output by igneous rock type demonstrates the importance of dolerite. This is partly because of the relatively widespread distribution of minor dolerite intrusions which, excluding the dykes, are usually large enough to accommodate modern quarries, and partly because of the high strength, abrasion resistance, polish resistance and exceptional consistency of many dolerites. Variations in properties do occur, due mainly to minor changes in mineralogy, but in general dolerites tend to have crushing strengths of 200 to 350 MN/m^2, aggregate abrasion values of 3.0 to 10.0 and an average PSV of about 59. They are suitable for most surfacing requirements, although they cannot provide the exceptionally high polished stone values of some gritstones; otherwise, they are suitable for most other aggregate uses.

Although granites and related rock types occur in very large masses they are not extensively exploited. They are often present in remote rural areas where vast resources are of little value in the face of limited demand. Although some coarse-grained granites tend to have relatively low crushing strengths, other granites meet specifications for roadstone and are intensively exploited. Examples include the Mount Sorrel mass in Leicestershire and the central part of the Lands End Granite.

Diorite is worked on a significant scale in Leicestershire and gabbro on a smaller scale in Cornwall. In both areas high quality aggregate is produced, but exploitation in the United Kingdom as a whole is restricted.

Minor intrusions of acidic igneous rock such as felsite or microgranite are worked at several localities for roadstone. Relative scarcity of deposits probably limits their exploitation but red coloured felsites worked in Northumberland, Strathclyde and Fife are of particular value.

Extrusive rocks, although abundant in some areas, are not extensively worked for aggregate except in Northern Ireland. The frequent presence of ash bands and vesicles, and the occurrence of successions of individual lava flows each with weathered upper surfaces, can cause difficulties in maintaining product quality. However, some volcanic rocks have been subjected to low-grade metamorphism which has increased the strength and consistency of the deposit. Such rocks include the Charnian volcanics of Leicestershire and the small outcrop of andesites in the Mendips, which together account for most of the output assigned to this category in England and Wales. In Scotland,volcanic rocks in the Clyde Plateau Basalts and Old Red Sandstone series are often sufficiently consistent to be worked for good quality roadstone.

Metamorphic rock (hornfels, gneiss and schist) and serpentinite, being relatively scarce or remote from industrial centres, are worked only occasionally. Some hornfelses have an exceptionally high crushing strength, and the strongest known aggregates currently produced in the United Kingdom belong to this category. Serpentinites on the other hand, being relatively weak with low resistance to abrasion, are used only on a very small scale for ornamental work, and relatively rarely for concrete aggregate. The terms gneiss and schist cover such a wide variety of rocks as to prohibit generalised statements on their properties as aggregate. However, they are worked at several sites in northern Scotland for roadstone.

In the building and ornamental stone industry, quarry location usually depends on traditional and aesthetic factors, as the finished material can bear the cost of transport over relatively long distances. In the

United Kingdom ornamental and dimension stone are at present largely produced from granites, although at one time dolerites and to a lesser extent felsites were widely used for setts and kerbs. Many of the older quarries had a long history of dimension stone production before becoming aggregate producers.

The distribution of igneous and metamorphic rock outcrops together with a variety of economic factors, have determined the grouping of quarries in the regions described briefly below.

South West England

In the Lands End granite, a large quarry is located in a zone of relatively fine-grained, high-strength material at Castle-an-Dinas, although other parts of the granite mass remain unworked. Aggregates are also produced at the Luxullian Quarry in the St. Austell granite and from quarries in the Carnmenellis granite, but the large mass of the Bodmin Moor and Dartmoor granites are not worked for aggregate in significant quantity, probably because of the availability of better quality aggregate from dolerites in these areas (Fig 8).

The granites of South West England are very popular for building and ornamental stone. The Carnmenellis granite is outstanding in this respect, being quarried by no less than eleven stone producers in a relatively small area between Falmouth and Helson. There are other producers, such as De Lank and Hantergantick quarries in the Bodmin Moor granite, and Merrivale quarry in the Dartmoor granite.

The gabbros of the Lizard complex are worked at Dean and West of England quarries, and the high quality aggregate produced is transported by coastal shipping mainly into South East England. Elsewhere on the Lizard the serpentines are exploited on a relatively small scale for hardcore and ornamental purposes.

At Penlee quarry, within the metamorphosed zone adjacent to the Lands End Granite, an altered dolerite is exploited on a large scale. The aggregate produced, which is transported by coastal shipping, has the highest crushing strength known among United Kingdom aggregates and is of particular value in Northern Europe where high strength is specified in road surfacing materials. The metamorphosed zone adjacent to the Dartmoor granite is also exploited at Meldon quarry for use as railway ballast. In Devon and east Cornwall the main producers of roadstone for local needs (New England, Pitts Cleave, Torr and Trusham quarries) are located in minor intrusions of dolerite.

There are no igneous rocks suitable for exploitation between the Dartmoor area and the Mendips, where a small outcrop of andesite is worked on a relatively large scale in two quarries at Stoke St. Michael.

The total output of quarries in Devon and Somerset in 1975 amounted to 1.5 million tonnes, of which approximately one third came from Somerset and most of the remainder from the dolerite quarries surrounding Dartmoor.

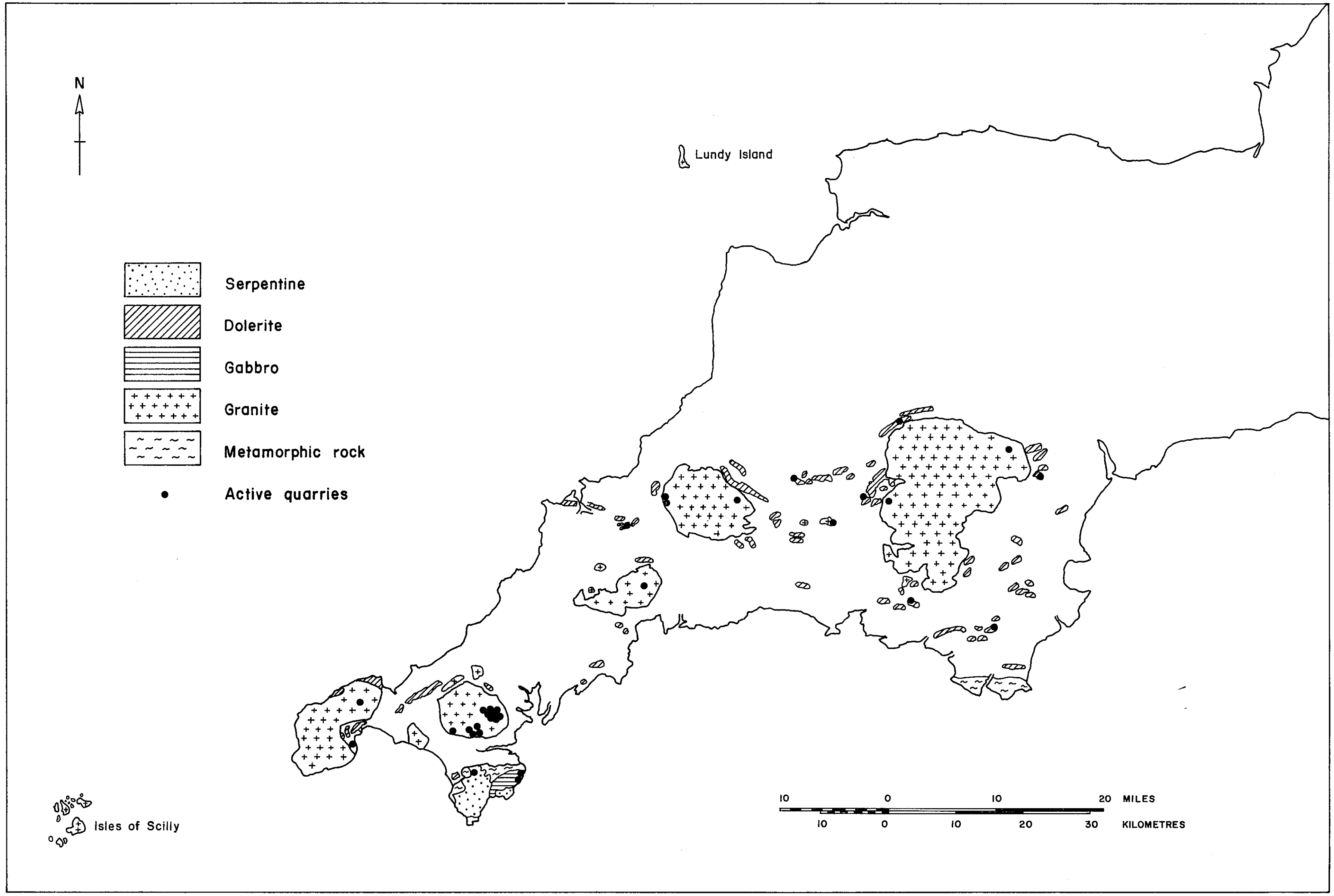

Fig 8 South West England: distribution of quarries in igneous and metamorphic rocks.

Table 20 Properties of aggregates from dolerite minor intrusions in Devon and Cornwall, based on data from five quarries

	Average	*Range*
Aggregate Crushing Value	14.6	11-18
10% Fines Value (kN)	299	209-358
Aggregate Abrasion Value	5.9	3.8-9.1
Aggregate Impact Value	10.6	6-17
Polished Stone Value	59.8	57-61
Specific Gravity	2.84	2.78-2.90
Water Absorption %	0.54	0.42-0.82

Sources: ECC Quarries Ltd (New England, Pitts Cleave, Greystone, Holwood and Torr Quarries);
Amey Roadstone Corporation (Trusham Quarry)

NB Data given in Tables 20-26 are intended for general guidance. The quality of material from individual quarries will vary to some extent as working progresses.

Table 21 Properties of aggregates from selected quarries in south-west England

Quarry	*Penlee*[1]	*Dean Quarry*[2]	*Castle-an-Dinas*[3]	*Moon Hill*[4]
Rock Type	*Metamorphosed dolerite*	*Gabbro*	*Granite*	*Andesite*
Crushing Strength MN/m^2	474	–	241	376
Aggregate Crushing Value	12	18	17	16
10% Fines Value (kN)	369	189	283	259
Aggregate Abrasion Value	2.0	4.1	5.4	5.2
Aggregate Impact Value	12	13	16	12.7
Polished Stone Value	43	62	56	59
Specific Gravity	2.72	2.75	2.62	2.68
Water Absorption %	0.64	0.30	0.65	0.88

Sources: 1 and 3 Amey Roadstone Corporation
2 Cawoods Road Materials Ltd
4 John Wainwright & Co Ltd

In Cornwall the output for the same year was 2.3 million tonnes, probably half of which came from large coastal quarries which ship their output out of the country. Penlee, Dean and West of England quarries load directly into boats of up to 3,000 tons capacity, and Castle-an-Dinas quarry sends most of its output through the Penlee loading facility. The inland aggregate producers supply the local market by road transport. Average properties of dolerites in South West England are given in Table 20, and of material from other selected quarries in Table 21.

Wales

Exploitation of igneous rocks in Wales is concentrated mainly on small basic intrusions and to a lesser extent on similarly-sized bodies of more acidic composition, frequently referred to as porphyry or microgranite (Fig 9 and Table 22). Otherwise there is some working of granite and metamorphosed rock in Anglesey. Extensive outcrops of volcanic material are worked at only one site.

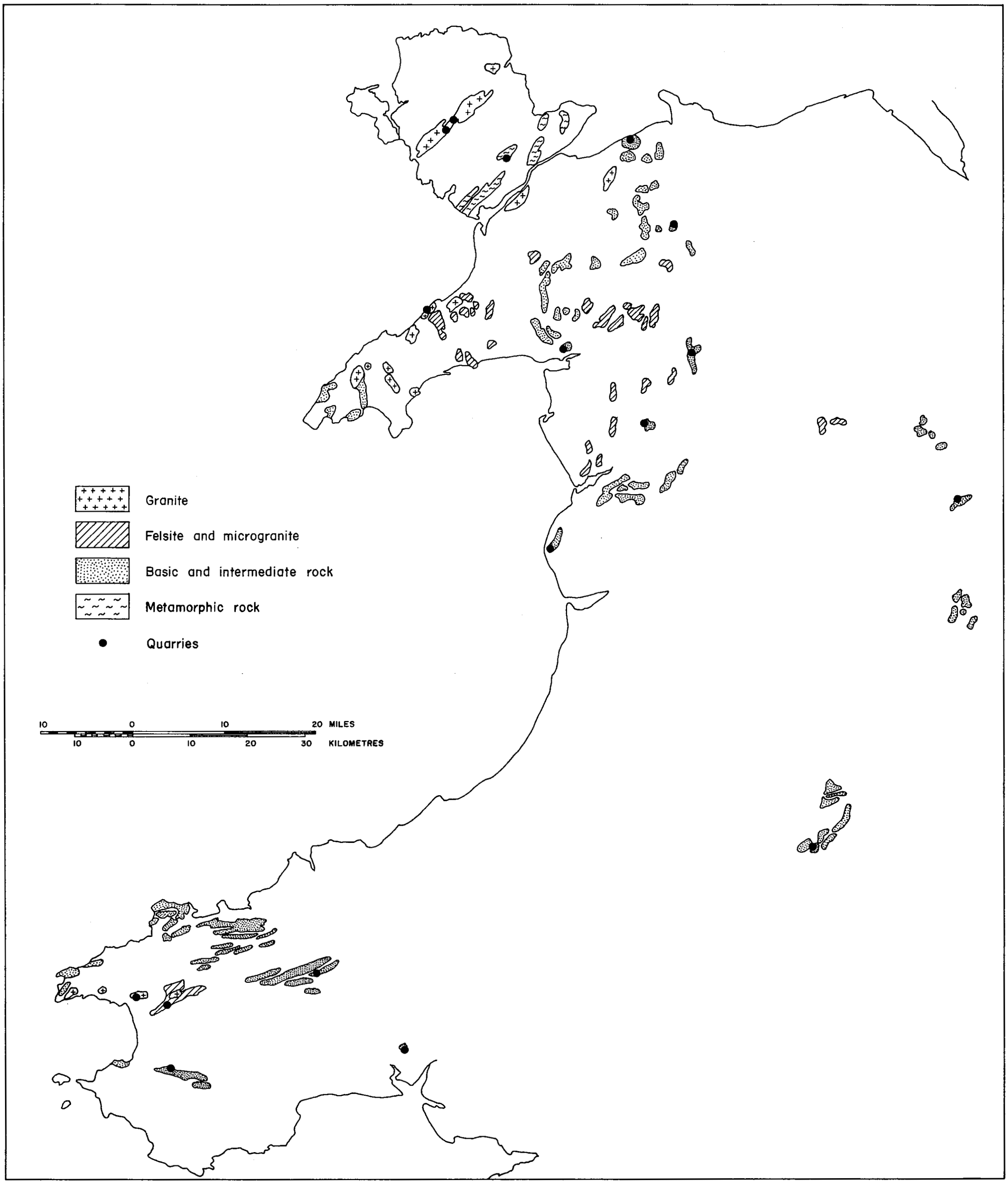

Fig 9 Wales: igneous intrusive and metamorphic rock outcrops.

Table 22 Properties of aggregates from selected quarries in Wales

Quarry	*Penmaenmawr*[1]	*Gwalchmai*[2]	*Arenig*[3]	*Minffordd*[4]
Rock Type	*Microdiorite*	*Coedana Granite*	*Porphyry*	*Dolerite*
Crushing Strength MN/m^2	358	206	306	220
Aggregate Crushing Value	12	19	12	11
10% Fines Value (KN)	–	–	340	–
Aggregate Abrasion Value	5	4	3	7
Aggregate Impact Value	14	19	14	10
Polished Stone Value	62	58	51	64
Specific Gravity	2.74	2.73	2.67	2.9
Water Absorption %	0.70	0.33	0.23	.003

Sources: 1 and 2 Kingston Minerals Ltd
3 Amey Roadstone Corporation
4 Pwllheli Granite Co Ltd

The largest igneous rock quarry in Wales is located in a microdiorite intrusion at Penmaenmawr near Conway. Roadstone and railway ballast are produced and transported largely into Merseyside although some is exported. The quarry has its own pier available for boats up to 1,000 tonnes together with a corresponding unloading dock in Liverpool. There are also extensive rail loading facilities.

At Llanwrst a volcanic rock outcrop consisting mainly of compacted tuff is worked for roadstone, some of which is transported by road into Cheshire and Merseyside. There are similar operations in small dolerite intrusions at Criggion near Welshpool, described previously, and at Builth Wells, both of which supply material over relatively long distances by road into south-west England and the Midlands. Otherwise the remaining igneous rock quarries in Wales tend to be relatively small and to supply purely local needs.

In Anglesey, the Precambrian Coedana granite is worked at two quarries for roadstone and concrete aggregate. A basic gneiss in the Mona complex is also worked at Gaerwen for roadstone. On the mainland producers are located in a porphyry intrusion at Arenig and in small dolerite intrusions at Minffordd near Portmadoc and at Towyn. In addition there are some small quarries producing hardcore often on an intermittent basis. The extensive quarries at Trevor in the Yr Eifl microgranite intrusion are now mostly derelict and aggregate production has ceased, but a portion of the site is still worked on a small scale for the production of road setts and other dimension stone. In south-west Wales at present the only workings of significant size are at Bolton Hill near Haverfordwest in Precambrian diorite and at Cerrigyrwyn quarry, 18 km south-west of Carmarthen, where a small dolerite intrusion in Old Red Sandstone is worked. In both cases the material is used locally for road surfacing. There are some small or intermittent workings in granite at Middle Hill near Solva, in dolerite at Garnwen, 30 km south of Cardigan, and in a felsite at Roch near Haverfordwest. Otherwise over much of south and central Wales surfacing material for local roads is obtained from quarries working greywackes, while material for concrete aggregate and base-course is largely derived from extensive workings in Carboniferous limestone.

East and West Midlands

In 1975 Leicestershire produced about 6 million tonnes of material from nine quarries located in small igneous outcrops which protrude above the New Red Sandstone of the Midland Plain. This is an exceptionally high county output and represents more than one third of the total English output. Intensive exploitation on this scale has taken place because there are no outcrops of comparable material to serve areas of high demand to the south or east of Leicestershire. These limited resources are therefore called upon to serve a wide area with roadstone (Table 23 and Fig 10).

Table 23 Properties of aggregates from selected quarries in Leicestershire

Quarry	*Mountsorrel*[1]	*Charnwood*[2]	*Whitwick*[3]
Rock type	*Granodiorite*	*Diorite*	*Volcanics*
Crushing Strength MN/m^2	–	217	243
Aggregate Crushing Value	18	17	16
10% Fines Value (kN)	199	259	279
Aggregate Abrasion Value	3.1	6.3	3.8
Aggregate Impact Value	18	15	14
Polished Stone Value	58	57	60
Specific Gravity	2.67	2.82	2.80
Water Absorption %	0.75	0.75	0.19

Sources: 1 Redland Roadstone Ltd
2 and 3 Amey Roadstone Corporation

The newly opened Buddon Wood Quarry, located in the Mountsorrel granodiorite and operated by Redland Roadstone Ltd is expected to have an initial output of about 1.0 million tonnes p.a. rising eventually to 2.4 million tonnes p.a. When fully developed it is expected to be the largest of the Leicestershire quarries and will probably be the largest igneous rock quarry in the United Kingdom.

Other large workings are situated in isolated outcrops of diorite and include Charnwood, Cliffe Hill and Grobey quarries. Croft Quarry, the most southerly of the Leicestershire quarries, is located in a group of outcrops of slightly different composition, intermediate between diorite and granodiorite, and usually identified as quartz diorite or tonalite. Whitwick and Bardon Hill quarries exploit Charnian volcanics of various types; commonly described as 'porphyries' in the trade, they are essentially a series of dacites and andesites which have been considerably strengthened by low grade metamorphism. The product has sometimes been described as tuff or agglomerate which, in accordance with the trade classification given in BS 812, has on occasion led to their being placed in the Gritstone Group.

In Warwickshire, sill-like lamprophyre intrusions within Cambrian strata are exploited at Griff and Mancetter quarries near Nuneaton, and there is some exploitation of Precambrian dolerite and volcanics exposed in quarries working the Hartshill quartzites.

In the West Midlands an intrusion of dolerite in the Carboniferous at Rowley Regis is worked at several large quarries on adjacent sites. These workings serve mainly the major conurbation in which they are situated. There is also an important producer of roadstone in a minor dolerite intrusion near Buxton, Derbyshire.

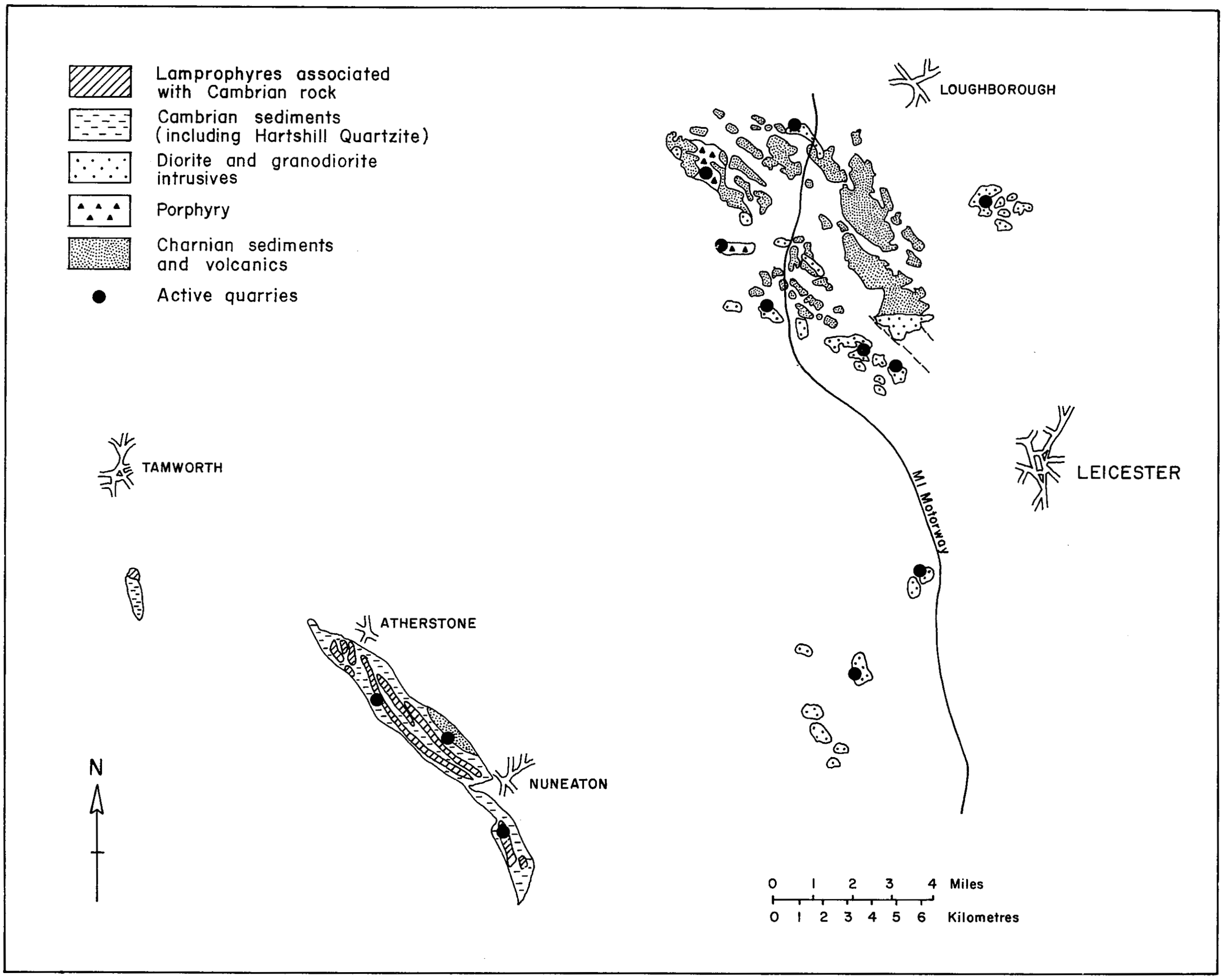

Fig 10 The Midlands: distribution of quarries in igneous and metamorphic rocks (counties of Leicester and Warwick).

The Welsh Borders contain many outcrops of rock suitable for road surfacing and lie near to the industrial parts of the West Midlands and North West Regions where such material is scarce. Hence, in recent years, there has been a continuing tendency to develop large quarries in Salop, and to some extent in convenient parts of Wales, to supply markets to the east.

In Salop, Amey Roadstone Corporation exploit dolerite sills and plugs at Llynclys near Oswestry, Clee Hill near Ludlow and More Quarry near Bishop Castle (Table 15). The quarry at Llynclys, being the most northerly of the group, supplies roadstone mainly into Merseyside, Cheshire and Greater Manchester while the others together with Criggion quarry in the Breidden Hills dolerite, just over the Welsh Border, tend to supply the Midlands.

Elsewhere in Shropshire a dolerite intrusion is worked by Shropshire County Council for use on local highways at Callow Hill, Minsterley. Near Wellington, Leaton Quarry exploits a dolerite intrusion in the Uriconian and Maddock Hill Quarry works a type of lamprophyre intruded into Cambrian sediments; products from both quarries tend to be used locally, the former producing coated roadstone, and the latter material for hardcore and sub-base.

In the Malverns quarrying activity is now greatly reduced. The two surviving quarries, Holly Bush and Gullet, work Malvernian metamorphic rocks on a modest scale.

Northern England

In Northern England exploitation of igneous rocks is centred on the Whin Sill which is worked at several points close to the coast in Northumberland, in the Haltwhistle-Barrasford area and at one quarry in Teesdale (Fig 11). In total these quarries produced close to 2 million tonnes of crushed dolerite in 1975. The material is used for concrete aggregate, roadstone and railway ballast (Table 24). It mainly satisfies local demand, although small amounts are shipped from Berwick into South East England and exported to other parts of Europe.

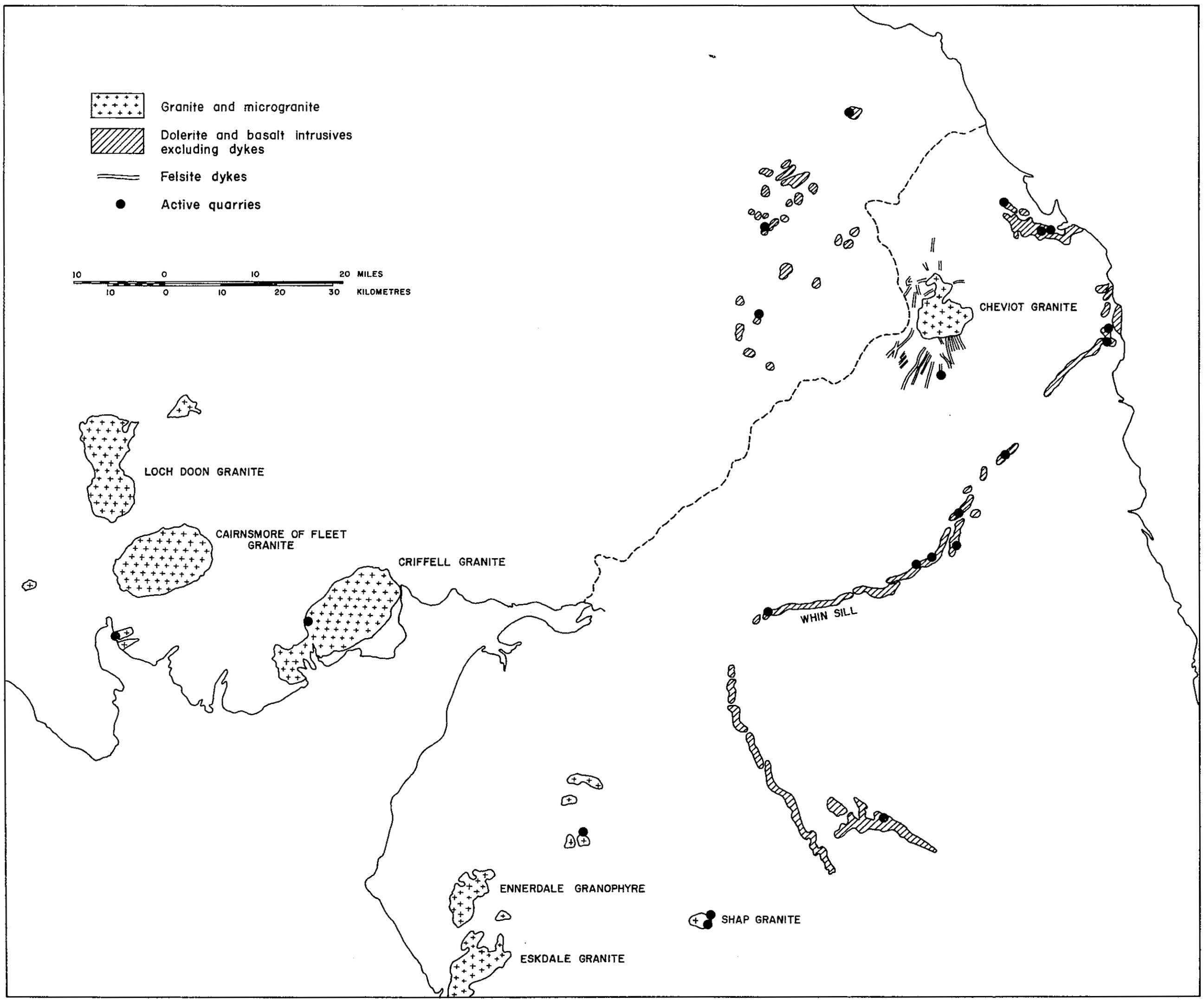

Fig 11 Northern England and Southern Scotland: distribution of quarries and igneous intrusives.

Table 24 Properties of aggregates from the Whin Sill dolerite based on data from eight quarries

	Average	*Range*
Crushing Strength MN/m^2	322	300-375
Aggregate Crushing Value	11.4	9-13
10% Fines Value (kN)	373	328-488
Aggregate Abrasion Value	4.2	3.0-5.0
Aggregate Impact Value	9.8	7-12
Polished Stone Value	57	54-61
Specific Gravity	2.90	2.84-2.94
Water Absorption %	0.61	0.2-1.00

Sources: Tarmac Roadstone Holdings Ltd (Walltown, Longhoughton, Barrasford, Middleton and Bolam quarries);

Amey Roadstone Corporation (Swinburne and Brada quarries);

Hargreaves Quarries Ltd (Highforce quarry)

Harden Quarry, near Rothbury on the eastern fringe of the Cheviot Hills, exploits a fine grained, red felsite associated with the Cheviots granite. This material is of particular value for the production of a red rather than the usual black road surface, either as a means of delimiting traffic lanes or for aesthetic reasons. It is distributed over the whole country and a little is exported.

In Cumbria the Shap Granite is worked primarily for use in concrete and exposed aggregate work. Building and ornamental stone was produced on a small scale until recently but this side of the industry has now ceased. Aggregate is produced on a larger scale from the 'Shap Blue' quarry in the metamorphic zone surrounding the granite. The rock, a biotite hornfels, is significantly stronger than the pink granite and is used mainly for railway ballast and roadstone.

At Threlkeld Quarry near Keswick, a minor intrusion of quartz felsite or microgranite in the Skiddaw Slates is worked on a moderately large scale to produce road surfacing material for local use.

Southern Scotland (Dumfries and Galloway and Border Regions)

In the Border Region several minor Carboniferous intrusions of dolerite in the form of small plugs or sills are worked from quarries at Duns, Jedburgh and Earlston. The material is used mainly for local highways although the northernmost quarry tends to distribute its products towards Edinburgh.

In Dumfries and Galloway, exploitation of igneous rock is virtually confined to two large granite quarries owned by the Scottish Granite Company. One of these, located near Dalbeattie, exploits the extensive Criffell Granite while the other, near Creetown, works a dyke-like body some 100 m wide known as the Creetown Granite. These quarries produce a light-coloured product which has been extensively used for major highway surfacing in northern England and southern Scotland. The Creetown Quarry, originally opened by the Mersey Docks and Harbour Board in the early nineteenth century to supply stone for Liverpool Docks, has berthing facilities for boats of up to 600 tons capacity and until recently shipped material to Glasgow (Fig 11).

In general, the demand for aggregates is small in this lightly populated area and there are ample resources. Where igneous rock is locally scarce, greywacke has been used on a considerable scale from workings in Lower Palaeozoic rocks.

Central Scotland (southern Strathclyde, southern Tayside, southern Central, Fife and Lothian Regions)

This area, between the Highland Boundary and Southern Upland Faults, produced approximately 10 million tonnes of igneous rock in 1975, or about two thirds of the total Scottish output. The greater part was contributed by some 28 quarries working in sills, and in places, plugs, of Carboniferous dolerite. In addition, there are five quarries working Carboniferous volcanic rocks. A phonolite intrusion is quarried for roadstone at Traprain Law and Old Red Sandstone extrusives are worked at Torphin Quarry, Edinburgh and at several sites in Tayside and adjacent parts of Fife. Red-coloured felsites are worked at two adjacent sites south-west of Lanark and at Lucklawhill in Fife (Fig 12).

The outstanding feature of this area is the importance of the Carboniferous minor basic intrusions. The abundant dykes, although worked in the past, are too narrow for modern quarrying operations and the industry is now concentrated on the sills, particularly on the Midland Valley Quartz-dolerite Sill. Consequently, in this area of little limestone and limited gravel resources, the sills and plugs often represent the major source of coarse aggregate.

In general they provide good quality material for road surfacing, concrete aggregate and railway ballast, although the PSV varies somewhat from one intrusion to another (Table 25). As they are usually intruded into softer material, the sills resist erosion and tend to create prominent hillside features with little overburden permitting of easy quarry working. In addition, many are sufficiently thick to accommodate working faces of 10 m or more at outcrop and as their composition is uniform over large areas there is little need for selective extraction.

Although the Carboniferous volcanics cover much larger areas than the minor intrusives, they are exploited on a relatively small scale. Operators report difficulties in working this type of material which in general appears to be more variable than the corresponding intrusives. The presence of tuff and vesicular material, and the weathered surfaces of upper parts of individual lavas flows, can result in areas of inferior rock which must be selectively removed or avoided if a high quality product is to be maintained. Similar considerations apply in general to the exploitation of the Old Red Sandstone extrusives although these are worked fairly extensively in Tayside.

For the most part quarries serve local needs, although several of the larger dolerite quarries have their own wharf or use a nearby harbour to ship material over longer distances. For example, Orrock quarry, Fife, ships roadstone to Greenwich. Cruicks quarry at Inverkeithing exports material to Europe and Hillhouse Quarry at Troon ships aggregate to Ardyne point for the manufacture of concrete structures for the offshore oil industry.

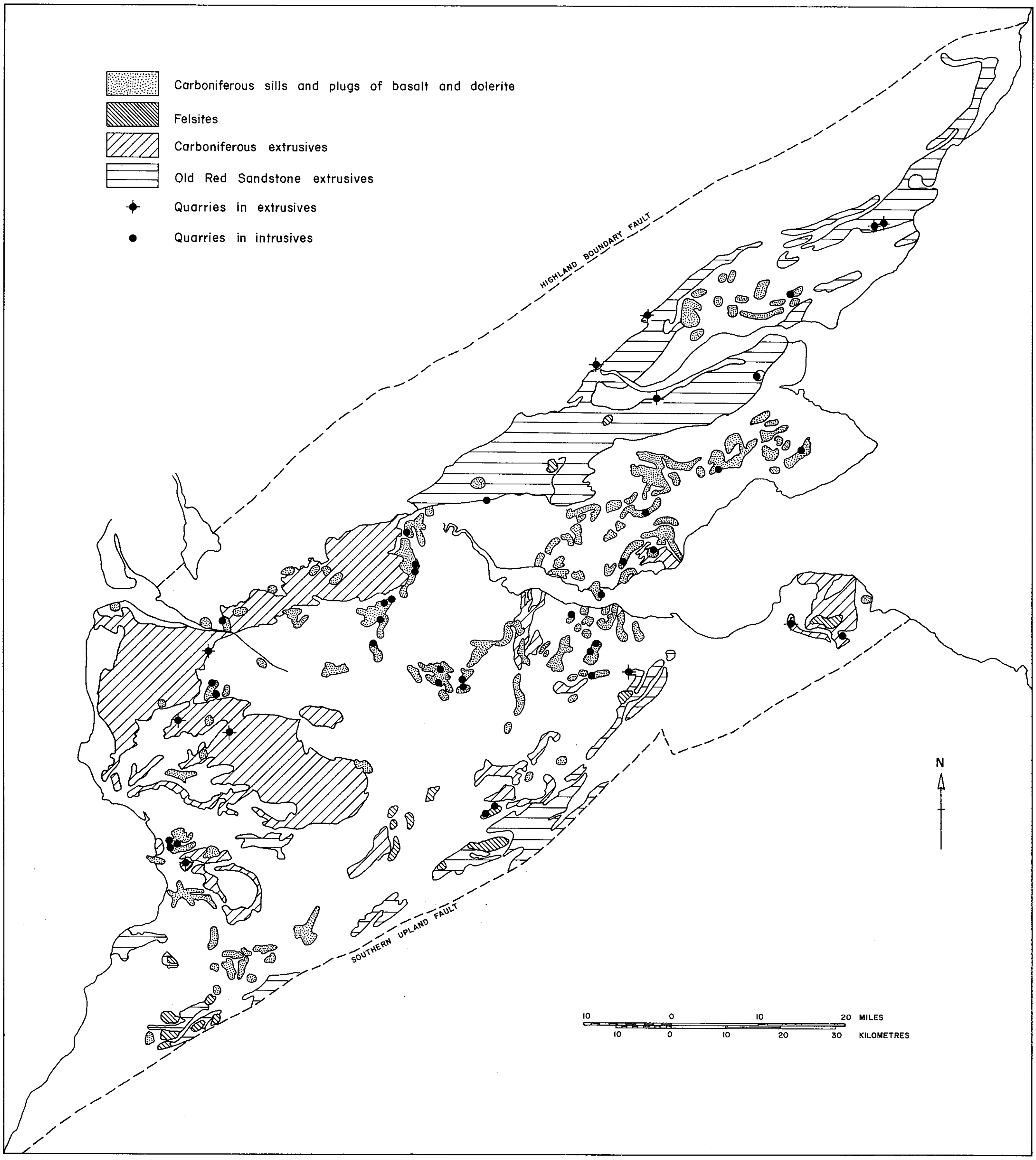

Fig 12 Central Scotland: important quarries and igneous formations.

Table 25 Properties of aggregate from quartz-dolerite sills in the Midland Valley of Scotland, based on data from seven quarries

	Average	*Range*
Crushing Strength	–	–
Aggregate Crushing Value	18.7	16-20
10% Fines Value (kN)	233	179-369
Aggregate Abrasion Value	5.6	3.8-9.0
Aggregate Impact Value	12.3	9-15
Polished Stone Value	60.7	58-63
Specific Gravity	2.88	2.82-2.94
Water Absorption %	1.72	1.6-1.9

Sources: Kings & Co Ltd (Cruicks, Blairhill, Kaimes, Craigpark and Croy quarries).

Wimpey Asphalt Co (Hillwood and Boards Farm quarries)

Northern Scotland (Highland, Grampian northern Central, northern Tayside, northern Strathclyde Regions and Islands areas)

The Aberdeen granites, long famous as a source of building and ornamental stone, are no longer worked for this purpose and all quarries in the City of Aberdeen have now ceased production. However, there are six quarries operating in the Hill of Fare Granite, three of these being in or close to the village of Kemnay, some 15 miles north-west of Aberdeen, with others at Tilleyfourie, Dyce and Dunecht. The material is mostly used for roadstone, concrete aggregate and concrete building blocks or 'reconstituted stone' (Fig 13).

The Peterhead Granite, one of the bodies mentioned in the Verney Report as a possible site for a large coastal quarry, is at present worked to provide material for the protection of offshore oil pipelines and for local industrial developments (Table 26).

The Grampian Region highway authority operates several widely distributed quarries to produce roadstone for local use, including two quarries in the extensive outcrops of basic plutonic rock and a quarry in metamorphic quartzite at Strichen.

In the north-west part of the Grampian Region, Moine metamorphic rock is worked for roadstone at quarries near Forres, Rothes and Aberlour. The material is often variable and requires selective working in some quarries, but nevertheless provides an adequate product, sometimes sold locally as 'grey whinstone'. Even where granites or other intrusives occur nearby, there is usually no history of previous working which would indicate any preference for igneous rock over the Moine. Similarly in the adjacent Highland Region, all local roadstone on the mainland is derived from Moine rocks at sites located near Bonar Bridge on the Dornoch Firth, Daviot near Inverness, Meadowside near Kingussie and Dornie, near Kyle of Lochalsh. At Banavie near Fort William a mixture of granite and Moine rock is produced. In addition there are other roadside quarries which may be worked occasionally for specific projects.

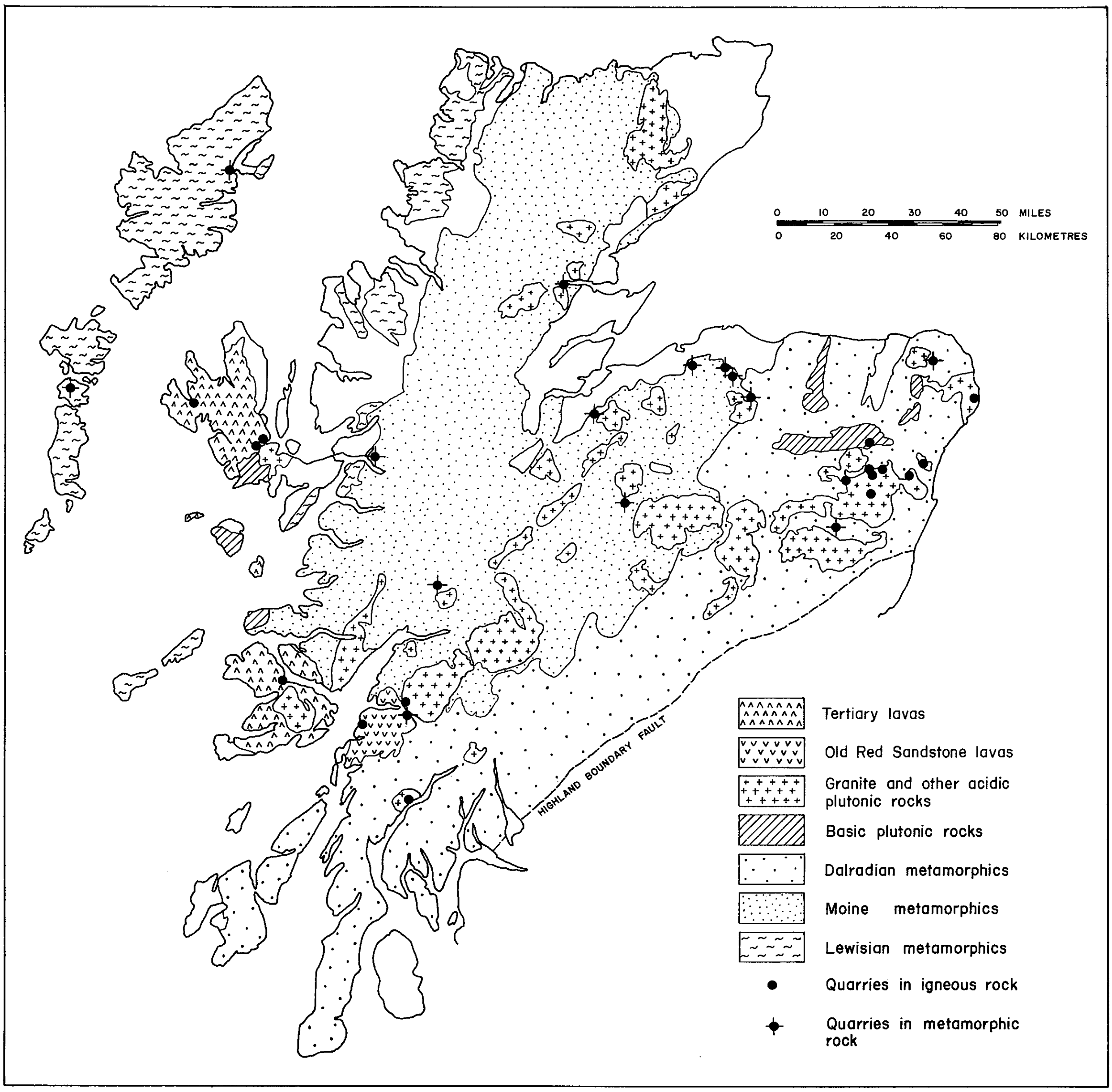

Fig 13 Northern Scotland: distribution of major quarries and outline geology.

Table 26 Properties of aggregates from selected quarries in northern Scotland

Quarry	*Furnace*[1]	*Stirlinghill*[2]	*Banavie*[3]
Rock Type	*Biotite-porphyrite*	*Peterhead Granite*	*Moine/Granite*
Crushing Strength	–	–	–
Aggregate Crushing Value	12.6	27	21
10% Fines Value (kN)	270	130	230
Aggregate Abrasion Value	2.5	3.4	3.2
Aggregate Impact Value	14.3	27	21
Polished Stone Value	52	49	51
Specific Gravity	2.64	2.63	2.70
Water Absorption	0.9	0.37	0.7

Sources: 1 Tilling Construction Services Ltd
2 and 3 Amalgamated Quarries (Scotland) Ltd

In view of their wide extent and variability, a description of the average properties of aggregates from Moine rocks would have little significance. However, data collected from three quarries gave PSV in the range 51 to 59 and AAV between 2.1 and 3.3. In general the material makes good roadstone although there would probably be difficulty in producing high PSV material.

In northern Strathclyde there is a quarry at Bonawe on Loch Etive which works the margin of the Etive granite. Transport of material is exclusively by ships of up to 1,000 tonnes capacity. At present only roadstone is produced, mainly for use on the west coast of Scotland, but formerly there was a large production of granite setts used in Glasgow and other cities.

On Loch Fyne another coastal quarry established for the supply of setts is located in a biotite-porphyrite at Furnace. Boats of up to 4,000 tonnes can be accommodated and production is over 1.0 million tonnes a year. Aggregate is exported to West Germany and to the construction site at Ardyne Point where it is used in concrete offshore platforms.

Elsewhere on the mainland there is a working for roadstone in altered Old Red Sandstone lavas adjacent to the Etive granite at Inverawe. The same lavas are also worked near Oban for fill.

In the Outer Hebrides, roadstone is mainly obtained from two quarries in the Lewisian at Stornoway and Benbecula. In the inner isles, Tertiary lavas are worked on Skye and Mull.

Several quarries have been opened in Shetland recently to supply material for new construction work associated with North Sea oil developments, including the protection of pipelines on the sea bed. The local authority also operates some roadstone quarries.

Northern Ireland

In 1975, 9.4 million tonnes of igneous rock, approximately 22 per cent of the United Kingdom total, was produced in Northern Ireland. Most came from workings in Tertiary basalt, which together with Lower Palaeozoic greywackes, comprise the major sources of coarse aggregate in the province (Fig 14).

The basalts, like other volcanic rocks, tend to be somewhat variable in quality due particularly to the prescence of weathered material in the upper parts of individual lava flows. However in many areas the flows are sufficiently thick and uniform for the successful production of a high quality aggregate suitable for road surfacing and concrete aggregate. Most of the material is used fairly close to the quarry and long distance haulage is unusual, although a few quarries with boat-loading facilities use coastal shipping for the transport of aggregate to Scotland and West Germany.

Quarrying of igneous rock other than basalt takes place on a relatively small scale. Coloured aggregate is produced from the Cushendun granite and some building and monumental stone is produced from the Mourne granite and the Dalradian schists in Co. Londonderry. Old Red Sandstone andesite and a gabbro in the Tyrone Igneous Complex, together with Tertiary dolerite intrusions in Co. Fermanagh and Co. Antrim are worked for aggregate.

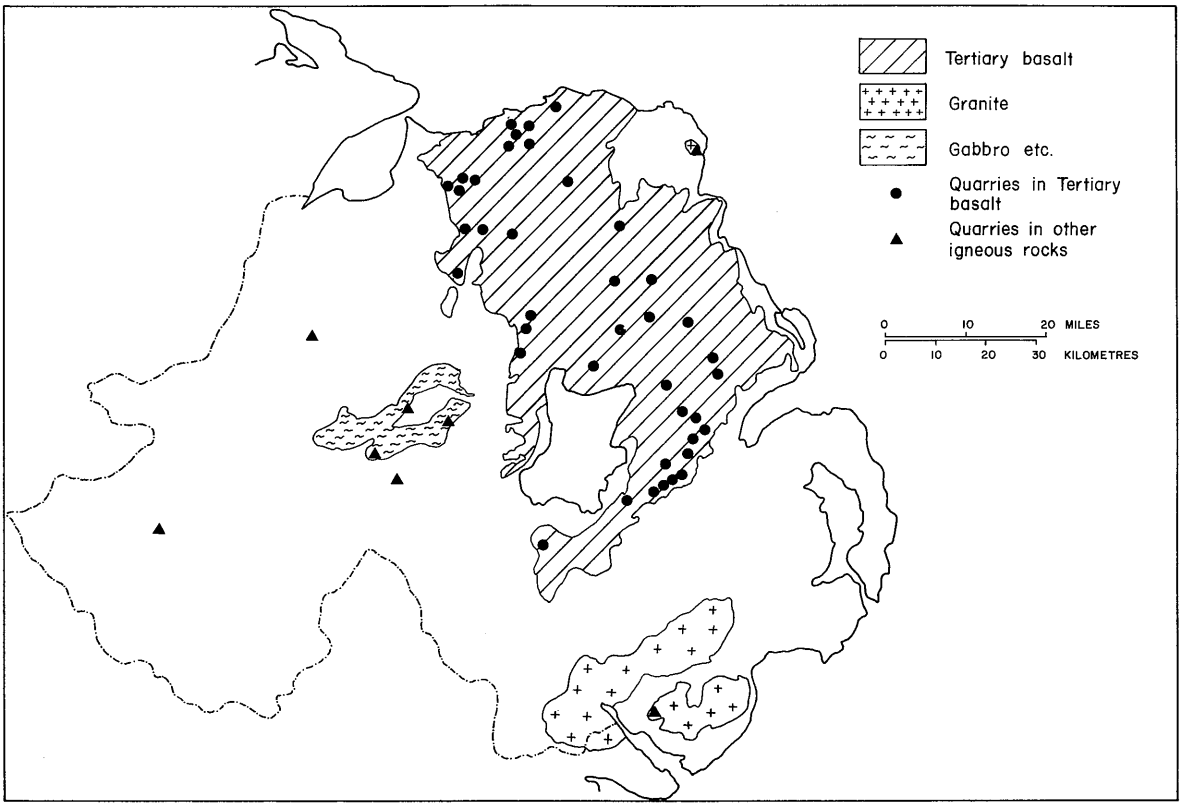

Fig 14 Northern Ireland: distribution of quarries and major igneous rock outcrop.

Channel Islands

At present there are two quarries on Jersey which work granite together with one granite and one gabbro quarry on Guernsey. The products provide the only source of aggregate on the islands. One of the quarries on Jersey has boat loading facilities and currently ships some of its output to Erith for use in the manufacture of concrete paving slabs.

Isle of Man

In the Isle of Man igneous rock is used essentially for roadstone, other aggregates being available for use in concrete. The main quarry is located in an altered dolerite intrusion near St. Johns and there is a smaller working in the Dhoon granite. Total production in 1976 amounted to approximately 90,000 tonnes. There is no export trade.

Technology

Quarrying

There are two fundamentally different concepts in quarrying, depending on the end use of the product. In the production of aggregate, the emphasis is on achieving maximum rock breakage for minimum expense, while in building stone production breakage must be very localised, sufficient only to release blocks from the quarry face without damaging them.

After overburden such as top soil, glacial drift and weathered rock has been stripped with a mechanical scraper and a face has been started, working for aggregates continues by drilling a line of vertical or inclined holes 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 nitro-glycerine-based or ammonium nitrate explosives. 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.

High explosives produce rock breakage by exploiting tensional failure. When an explosive-filled borehole detonates, the force is initially greater than the compressive strength of the rock which results in intense shattering around each hole. Beyond this zone, the shock waves pass through the rock leaving it undisturbed until they reach a rock interface, such as the face of a quarry, where they are reflected. If at this point the force exceeds the tensional strength of the rock, it will fracture along the interface. After blasting the broken rock is usually picked up by a front-end loader and transported in large rubber-tyred trucks to a crushing and screening plant.

On grounds of safety, quarrying practice now tends to avoid high single face workings and it is becoming more usual to work in a series of benches some 10 to 20 m high, although a limited number of igneous rock quarries still retain high faces. In recent years there has also been a tendency to use angled rather than vertical holes to produce bench faces inclined at 60-80°. This reduces the chances of formation of overhanging faces and the severity of rock falls; there has also been some improvement in blasting efficiency.

In some quarries, the use of explosives has been discontinued and extraction is carried out by 'ripping' with a large earth moving machine carrying a rear mounted single tooth which loosens the rock sufficiently for it to be picked up with an excavator. The advantages of this method are largely environmental in that there is no ground vibration or danger from flying fragments. Ripping is used for working weaker rock types and occasionally, for strong rocks where these are well jointed. Thus it is rarely used in igneous and metamorphic rock extraction and is more commonly applied in the working of sedimentary rocks.

In building and monumental stone quarries extraction of crude block is often done by hand, using wedges to open out joints or drill holes. Otherwise a gunpowder type of explosive may be used to lift the rock, but not a high explosive of the type used in aggregate working. Occasionally some aggregate quarries may sell large blocks, produced fortuitously, for dressing into building stone, but it is more usual for quarries to specialise in either building stone or aggregate production. In a few monumental stone quarries a relatively new technique known as flame cutting is used by which large blocks of stone are cut from the face using a high temperature flame produced by an oxygen-fuel oil mixture.

Processing

Processing of quarried igneous and metamorphic rock for aggregates invariably involves crushing and screening. In most large igneous rock quarries the primary section of a fixed plant consists of a jaw or gyratory crusher which reduces material to some nominal coarse size in the range 15 to 25 cm. Capacities of primary crushers may be large, for example a 2,000 tonnes per hour gyratory crusher has been installed at Buddon Wood Quarry, although units of up to 500 tonnes per hour are more usual. After primary crushing, fines may be screened out before the bulk of the material passes to a surge pile which usually accommodates several weeks output, enabling the plant and quarry to function independently over relatively long periods.

Material from the surge pile passes into further size reduction operations with associated screening to produce saleable size fractions. Secondary, tertiary and quaternary crushing is often involved using various combinations of either gyratory, cone or jaw crushers, with screening at each crushing stage in addition to extensive final screening. A final washing stage may be incorporated particularly if fines are present which would inhibit bonding with bitumen. Many of the larger quarries have a bitumen coating plant on site for the preparation of pre-coated roadstone chippings, others have asphalt plants and in some areas ready mix concrete plants.

In some of the smaller quarries mobile crushing and screening plants may be used. These units are of particular value in short-life workings which would not repay the installation cost of a permanent plant, or where existing permanent plant cannot cope with a sudden increase in quarry output.

Cutting, dressing and polishing of building and monumental stone involves various techniques which can only be described briefly. Usually the stone is extracted from the quarry in crude blocks of approximate dimension 2 m x 1 m x 1 m, and is fed to a frame saw which consists of several diamond-tipped rectangular saw blades arranged in parallel in a rectangular frame attached to a reciprocating drive.

The slabs produced by the primary cutting may be cut into smaller blocks or trimmed by means of diamond-impregnated circular saws. The surface is often hand finished in building stone, but for ornamental stone treatment may involve working with various mechanical carving tools. Polishing of slabs usually involves mechanical planing followed by grinding under successively finer grades of silicon carbide, and a final polishing stage using tin oxide abrasive.

Prices and other economic factors

In the aggregate industry, transport cost is the major variable affecting the price paid by the consumer. As an approximate guide at 1976 prices, a cost of 2p per tonne-km, sometimes with a loading charge of 20p per tonne, can be assumed for road transport in loads of at least 10 tonnes with an empty return journey. Costs increase significantly in congested urban areas; conversely there is a saving on motorways and with larger trucks.

Thus dry chippings from Leicestershire for delivery by road to Chichester in minimum 10 tonnes loads were quoted at £6.44 per tonne to the local highway authority in 1976. This refers to 6 mm, 10 mm and 14 mm sized material, the price being independent of size, transported by road over a linear distance of approximately 180 km. Another quarry was prepared to deliver similar material to the same point from 130 km away at prices of £5.37, £5.76 and £5.59 per tonne for 14 mm, 10 mm and 6 mm material respectively.

The ex-pit price of aggregates varies somewhat according to local factors, notably the availability of alternative materials and the type of market being served. Finer material is usually slightly more expensive than the coarser size fractions due to the higher crushing costs. However in general, sized aggregates suitable for roadstone were sold within the range £1.50 to £3.00 per tonne ex-pit in 1976. For example, in mid-1976 a typical quarry working the Whin Sill was charging £1.50 per tonne for material in various size ranges below 75 mm. Similar doleritic material in the Midlands was being sold in the range £2.00 to £2.20 per tonne, and an acidic rock with distinctive colouring was priced at £2.50 to £3.00 per tonne for size ranges below 25 mm.

In the building and ornamental stone industries, prices obviously vary according to the amount of preparation which goes into the finished article. As a general guide the following approximate prices for granite were quoted at De Lank Quarry, Cornwall in mid-1976:

Slab cut to size 38 mm thick, with one polished surface	£48/sq metre
Slab cut to size 38 mm thick, with one fine axed surface	£48/sq metre
Slab cut to size 38 mm thick, with sawn surface	£46/sq metre

Monumental stone: articles priced individually on the approximate basis of £110-130/m^2 of finished surface

Random walling stone £10/tonne

Aggregates for exposed aggregate work, in individual size fraction between 38 mm and 3 mm

Silver grey	£12/tonne
Silver bronze	£8/tonne

Land use

Information on land use for igneous and metamorphic rock quarrying is available for England and to a lesser extent Wales. The following account applies, therefore, essentially to igneous rock quarrying as there is relatively little working of metamorphic rocks in these areas.

It is thought that igneous rock quarries consume about 30 hectares of land a year in England and Wales. At 1 April 1974, there were over 2,700 hectares of land in England with valid planning permission for surface extraction of igneous rock. This land was distributed between five Economic Planning Regions: the South West (29 per cent), West Midlands (24 per cent), East Midlands (22 per cent) Yorkshire and Humberside (14 per cent) and Northern (11 per cent).

The largest county areas in England covered by igneous rock permissions were in Leicestershire with 602 hectares followed by Shropshire and Cornwall with 445 and 339 hectares respectively. The remaining 1,325 hectares were distributed between nine other counties with relatively extensive areas occuring in Northumberland, Devon, Cumbria, Somerset and West Midlands.

Part of these permitted areas have already been worked (pits and excavations) or affected by working (spoil heaps, tailings lagoons and plant). The total permitted area not yet affected by working on 1 April 1974 was 1,424 hectares. Of this 33 per cent was in the Northern Region, 26 per cent in the South West, 24 per cent in the West Midlands, and 17 per cent in the East Midlands. The largest permitted areas not yet affected by working at the time of the survey were in Shropshire (302 hectares), Northumberland (277 hectares), Leicestershire (235 hectares) and Cornwall (175 hectares) which together constituted 70 per cent of the total unaffected area.

Igneous rock plays an important part in the structure and scenery of a number of amenity areas including both National Parks and Areas of Outstanding Natural Beauty. Notable examples are the Dartmoor and the Snowdonia National Parks and the Bodmin Area of Outstanding Natural Beauty. Other amenity areas with large outcrops of igneous rock are the Lake District

National Park, Cornwall National Heritage Coast and the Malvern Hills and Shropshire Hills Areas of Outstanding Natural Beauty. A few important igneous rock quarries are in the West Midlands Conurbation Green Belt.

Quarrying operations require planning permission under the Town and Country Planning Acts which provide for the imposition of conditions to control *inter alia,* the restoration of sites. The 1974 survey suggested, however, that half of the total area permitted for igneous rock working in England is not covered by adequate conditions. This is largely because conditions attached to consents issued in the 1940s and 1950s were rarely as stringent as those now imposed. The survey also showed that spoil heaps, tips and plant occupied about 15 per cent of the total working area of quarries.

A considerable proportion of waste may be produced, especially in relation to small granite quarries in the South West, where only high quality stone can be used for building purposes and the local market for waste rock for use as fill is limited.

The amount of land consumed by individual quarries is variable and depends on the output and depth of the workings. In general, however, quarries with yields of over 800,000 tonnes per hectare, corresponding to an average depth of over 30 metres, are rare. The majority in England and Wales have yields in the range 15,000 to 400,000 tonnes per hectare. A high proportion of the shallowest sites are in Devon and Cornwall and are mainly concerned with the production of building and ornamental stone. The largest quarries are often linked for distribution of the products to major markets by rail, for example, from Leicestershire to the South East of England.

Most igneous rock quarries are in upland areas and are worked dry, above the water table. The method of after-treatment depends on the type of working, the quantities and character of waste materials and fill available and the location. At least the quarry floor can usually be restored by spreading top-soil on waste rock and any overburden available. Some sites close to towns may be used for tipping of solid domestic and industrial wastes, subject to safeguards which include, notably, hydrogeological considerations.

Aggregates supply has been considered recently by the Advisory Committee on Aggregates (the Verney Committee). Their report emphasised, with regard to hard rock, the importance of transport of aggregates by rail, and mentioned the long term possibilities of developing underground stone mines and large scale coastal quarries.

Detailed studies of reserves, production and distribution of aggregates are being carried out currently by a series of Local Authority Aggregates Working Parties set up on an Economic Planning Region basis.

Substitutes and future supplies

Gravel, crushed limestone and sandstone are natural alternatives which compete for many of the uses of crushed igneous and metamorphic rock aggregates. In some respects the alternatives are preferable. Gravel is usually preferred as the coarse aggregate for concrete. Limestone is cheaper to crush and makes a better bond with bitumen for use in the lower levels of roads. Some types of sandstone have adequate resistance to abrasion and a higher resistance to polishing than any igneous rock. This makes them superior as road surfacing material, although many igneous rocks are entirely adequate for present highway surfacing specifications. Igneous rock has a clear technical advantage only as railway ballast. Thus if all types of rock were equally available in all locations, igneous or metamorphic rock would probably account for a much smaller proportion of total production.

However, it is a fundamental feature of British geology that rocks suitable for aggregate and related uses are far from uniformly distributed (for example, see Mineral Dossier No. 17 for the distribution of the best sandstones for road surfacing). Economic factors (notably transport costs) therefore determine that igneous rocks are the main source of coarse aggregate in areas where other suitable material is absent or scarce (for example Cornwall, part of north-east England, much of Scotland and Northern Ireland). A regional distribution of coarse aggregate production divided into the main rock types is given in Table 27 and Fig 15.

In recent years increasing attention has been paid to the possibility of waste and alternative materials substituting for natural aggregates. A full review of the location, disposal and uses of these materials in Great Britain has been made by Gutt *et al* (1974). The major materials with potential as aggregates included the following:

Waste	*Production million tonnes*	*Stockpile million tonnes*	*Comment on usage*
Colliery spoil	50	3,000	7-8 million tonnes per annum used mainly for construction fill, brickmaking and light-weight aggregate.
China clay waste	22	280	About 1 million tonnes per annum used mainly for fine aggregate and construction fill.
Slate waste	1.2	300+	Used for expanded slate aggregate and construction fill.
Pulverised fuel ash (Pfa)) Furnace bottom ash (Fba))	9.9	not known	6.3 million tonnes per annum used for construction fill, light-weight aggregate etc.
Furnace clinker	2.3		All used, mainly in concrete block making.
Blast furnace slag	9		Nearly all used as roadstone, railway ballast, filter medium, concrete aggregate etc.
Steel making slag	4	not known	2 million tonnes per annum returned to blast furnace the rest goes for construction fill or roadstone.

Blast furnace slag has for many years been utilised as high quality roadstone, and to a limited extent substitutes for natural surfacing materials. Also calcined bauxite, a manufactured material, has been found to have an exceptionally high resistance to polishing under traffic as it possesses a polished stone value higher than any natural roadstone tested; it is very much more expensive however.

The Advisory Committee on Aggregates (the Verney Committee) has given comprehensive guidance on meeting the nation's future needs for aggregates. The Committee recognised that there is no prospect of waste materials completely supplanting natural aggregates, or even becoming a major source of supply. They recommended, however, that the use of waste materials should be encouraged by, for example, ensuring that specifications are not unnecessarily restrictive. The Committee also encouraged the Building Research Establishment to continue its work on the production of dense concrete aggregate from colliery spoil. However, this could have only a limited effect on the demand for igneous rock, as only approximately 10 per cent goes for concrete aggregate. Research is also being encouraged into such techniques as cement stabilisation, by which low-grade wastes may be converted into materials suitable for high quality bulk fill. Again, even if successful, this could lead to only limited substitution for igneous rocks.

In the case of building and ornamental stone, demand and the scope for substitution are determined by aesthetics and architectural fashion. Demand is so small in relation to the resources that there is no risk of shortages.

Total resources of igneous and metamorphic rock in the United Kingdom are enormous, so that there will never be an absolute shortage of supply, but the relatively high cost of transport and preference for certain rock types has resulted in intensive exploitation adjacent to some areas of high demand.

Igneous rocks currently under heavy pressure include the intrusives and volcanics of Leicestershire, together with minor intrusions, usually of dolerite, adjacent to the more populous parts of the country. These include several scattered sill-like intrusions in the West Midlands and Welsh Borders, the Whin Sill, the Midland Valley Quartz-dolerite Sill in central Scotland, the dolerite intrusion surrounding the Dartmoor granite and the andesite lava in the Mendips. If reserves in these areas become exhausted, other igneous rock or alternative natural aggregate will have to be carried greater distances, with a consequent increase in cost.

Table 27 Regional production of coarse aggregate in the United Kingdom, 1975

millions tonnes

Economic Planning Region	*Gravel*[1]	*Limestone*[2]	*Igneous rock*[3]	*Sandstone*[4]
Northern	1.64	7.78	2.45	0.49
North-west	0.86	2.48	–	2.56
Yorkshire and Humberside	2.84	9.38	–	1.42
West Midlands	6.00	3.30	4.02	2.18
East Midlands	5.98	12.57	5.94	0.12
East Anglia	5.04	0.65	–	–
South East	26.00	1.73	–	0.19
South West	3.47	18.64	3.77	0.21
Wales	1.62	12.15	1.80	1.45
Scotland	8.99	0.40	14.35	1.22
Northern Ireland[5]	2.00	0.80	9.37	3.19

1 Includes hoggin and marine dredged gravel landed at home ports but excludes all types of sand.

2 Includes chalk used for construction purposes (Great Britain total 1.45 M tonnes) but excludes all limestones used for cement making and non-construction purposes. Also includes building stone (Great Britain total 0.22 M tonnes).

3 Includes building stone (Great Britain total 0.02 M tonnes) and metamorphic rock.

4 Excludes building stone.

5 End use statistics are not available for Northern Ireland. Total production is given for sandstone and igneous rock. Estimates are given for the production of gravel and limestone used for construction purposes as defined for Great Britain.

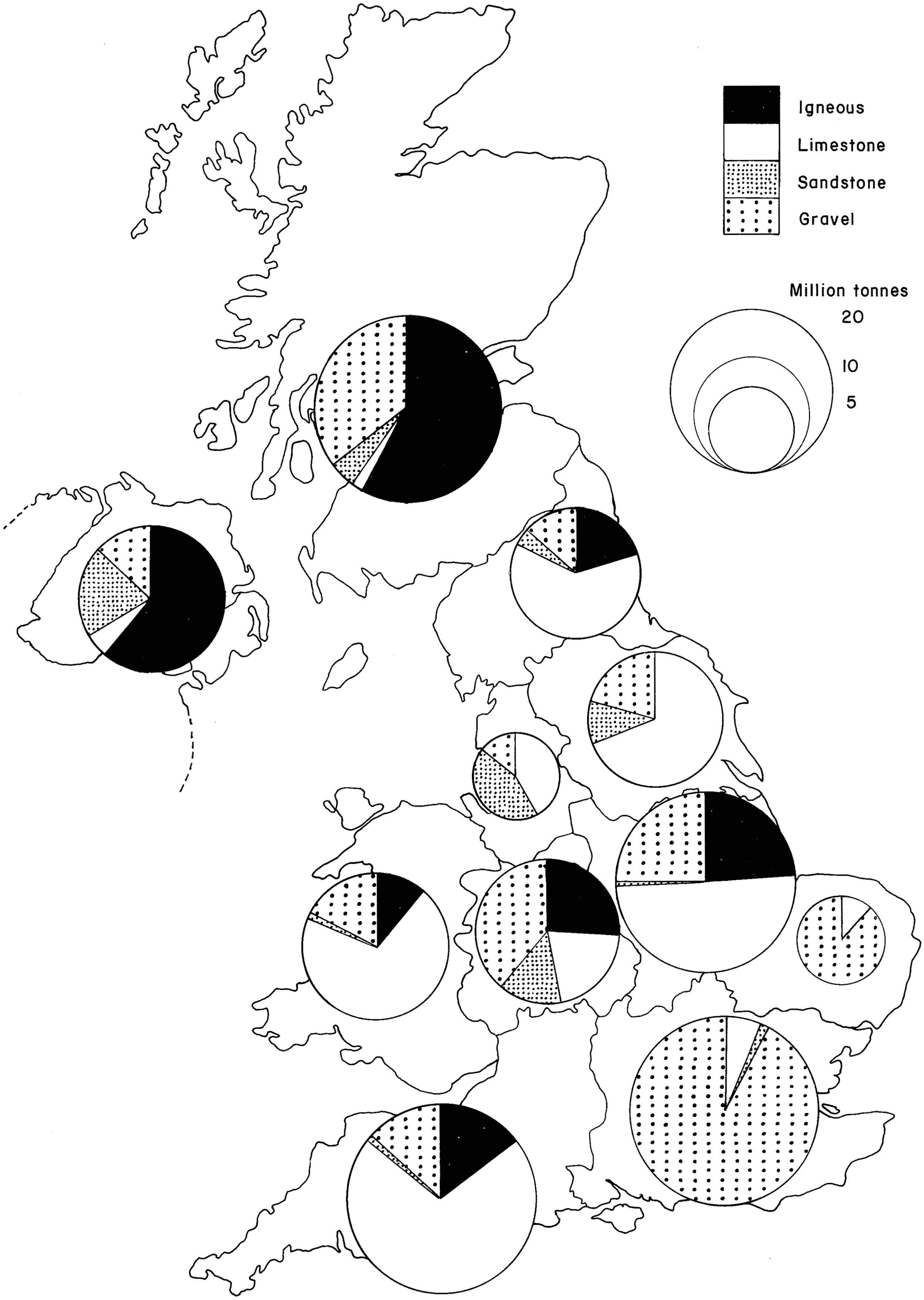

Fig 15 Regional distribution of coarse aggregate production.

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