Mineral Resources
Consultative Committee

Mineral Dossier No 13

Gypsum and Anhydrite

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Titles in the series

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Preface

The Mineral Resources Consultative Committee consists 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 has led the Committee to undertake the collation of the factual information at present available about those minerals (other than fossil fuels) which are now being worked or which might be worked in this country. The Committee has 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 are now being published for general information.

Acknowledgments

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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
cubic metres (m^3) = cubic feet x 0.028317
kilogrammes (kg) = pounds x 0.45359237
tonnes (1000 kg) = long tons x 1.01605

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Summary

Gypsum ($CaSO_4.2H_2O$)and anhydrite ($CaSO_4$) are naturally occurring forms of calcium sulphate. Gypsum is a very important raw material for the building industry, being used principally in the manufacture of plaster and plasterboard, and as a retarder in Portland cement. Anhydrite is used in the manufacture of sulphuric acid and cement clinker and was used in the United Kingdom until 1971 in the production of the fertiliser ammonium sulphate.

Gypsum and anhydrite are widely distributed in the United Kingdom, occurring mainly in rocks of Permian and Triassic age in the East Midlands and northern England and, to a lesser extent, in Upper Jurassic strata in southern England. Beds from 1.8 to 4.5 m thick are worked, either by opencast or underground mining methods. There are substantial workable reserves of both minerals, although total resources of gypsum are much more limited because most gypsum deposits occur near the surface and pass into anhydrite at shallow depth. A large, potentially important source of calcium sulphate is phosphogypsum, which is obtained chiefly as waste in the manufacture of phosphoric acid.

The United Kingdom is one of the world's major producers of gypsum and anhydrite, ranking sixth in 1973, when the combined output of these minerals amounted to some 4.2 million tonnes. Of this total 3.8 million tonnes was gypsum, of which about 35 per cent came from Nottinghamshire, 25 per cent from Sussex and 22 per cent from the Vale of Eden south of Carlisle. The remainder was produced in Staffordshire and North Yorkshire. Most of the anhydrite is produced near Whitehaven in Cumbria, although small quantities are still mined in the Vale of Eden. Imports, consisting essentially of raw gypsum and gypsum plasters are relatively small, and amounted to 211,000 tonnes in 1973, almost entirely from the Irish Republic and France. Exports are very small, amounting in 1973 to about 8,000 tonnes of gypsum plaster which was shipped principally to the Irish Republic. In addition, some 6,800 tonnes of raw gypsum was exported, mainly to the USA, as well as nearly 2,600 tonnes of plasterboard, chiefly to France.

The major gypsum producing company in the United Kingdom is British Gypsum Limited, the largest subsidiary of BPB Industries Limited. Gypsum is also produced between Nottingham and Grantham by The Associated Portland Cement Manufacturers Limited and, on a much smaller scale, by H J Baldwin and Company Limited near East Leake, also in Nottinghamshire. Anhydrite is produced almost entirely by Albright and Wilson Limited, although small quantities are produced also by British Gypsum Limited.

Definition and mode of occurrence

Gypsum ($CaSO_4.2H_2O$), the dihydrate, and anhydrite ($CaSO_4$) are the naturally occurring forms of calcium sulphate. The name *gypsum* is derived from the Greek *gupsos*, which itself is thought to have been derived from the Greek words for 'earth' and 'to cook' and was probably applied to the natural mineral or may have denoted calcined gypsum. When pure, gypsum is colourless to white and shows very little variation in chemical composition. In terms of oxides it contains 32.5 per cent calcium oxide, 46.6 per cent sulphur trioxide and 20.9 per cent water. A perfect platy cleavage, giving crystals a tabular habit, and a hardness of 1.5 to 2 on Mohs' scale are diagnostic properties. Commercial deposits of gypsum rarely approach this purity, but usually contain varying amounts of clay and shale, anhydrite, limestone, dolomite, iron compounds and silica; the water content may also vary. Such gypsum is usually massive, consisting of an aggregate of intergrown crystals and may be grey, brown, red or pink, depending on the impurities present. It is slightly soluble in water, but is otherwise an inert mineral, resistant to chemical change and with marked fire-resistant properties because on heating water is driven off. The solubility increases with temperature up to 42°C, above which the gypsum transforms to anhydrite. This causes the formation of very hard scale in boilers when calcium sulphate is present in the feed water. Calcium sulphate in natural water causes permanent hardness.

Anhydrite, when pure,contains 58.8 per cent sulphur trioxide, equivalent to about 23.5 per cent sulphur, and 41.2 per cent calcium oxide. It has no water of crystallisation, dissolves in water more slowly than gypsum, and eventually will hydrate to this mineral, a process which is accelerated by fine grinding. The mineral occurs as massive, usually granular, aggregates that are white to pale shades of grey, blue, brown or red. With a hardness of 3 to 3.5, it is also much harder than gypsum, producing a characteristic spark when struck with a pick. Anhydrite crystals show three good cleavages at right angles to one another.

Selenite is a transparent or translucent crystalline variety of gypsum, with a tabular habit. The compact, massive, fine-grained form, somewhat resembling marble and used as an ornamental stone, is known as *alabaster:* the fibrous silky lustred variety is known as *satin-spar* and is also used to some extent for ornamental purposes. *Gypsite* or *gypsum earth* is a term referring to a mixture of gypsum, clay and sand.

When heated at temperatures between 150° and 165°C., approximately three-quarters of the water of crystallisation in natural gypsum is driven off as steam. The product, known as calcined gypsum, gypsum plaster or *plaster of Paris* (because it was originally obtained from gypsum quarried at Montmartre) is principally the *hemihydrate* ($CaSO_4.\frac{1}{2}H_2O$) which,with the addition of water, hydrates and reverts to gypsum. Heating gypsum at higher temperatures produces anhydrite. There are two forms of the hemihydrate, which are known as α-hemihydrate and β-hemihydrate respectively, the former being the more stable and possessing markedly different physical properties because of its much larger crystal grain size. The hemihydrate occurs in nature as the mineral *bassanite.* Natural or β-anhydrite, is stable to about 1,200°C., although decomposition may start at around 900°C. β-anhydrite also arises as a by-product of hydrofluoric acid manufacture and from dead-burning gypsum. α-anhydrite is the form of anhydrous calcium sulphate present above 1,200°C.

Calcium sulphate crystallises in either the anhydrite, hemihydrate or dihydrate (gypsum) forms as a by-product in the manufacture of phosphoric acid. Most commercial phosphoric acid processes produce the dihydrate, but in some it is the α-hemihydrate that is crystallised out. To all three forms the term *phosphogypsum* is generally applied. *'Mineral white'* or *'terra alba'* is the name given to ground gypsum used as a filler in the paint and other industries.

The largest and commercially most important deposits of gypsum and anhydrite occur as beds which may persist over considerable areas with little change in either quality or thickness. They are frequently interbedded with limestones, shales, mudstones, clays, dolomite, rock-salt and, locally, potassium-bearing salts. Gypsum and anhydrite are among the first minerals to be precipitated from evaporating sea-water which contains about 0.14 per cent by weight of calcium sulphate. Further evaporation results in the precipitation of rock-salt (halite) and potassium and magnesium-bearing salts. The mineral precipitated is greatly influenced by temperature and the concentration of other minerals in solution. There are differences of opinion as to whether gypsum or anhydrite is the first calcium sulphate mineral to be precipitated. According to experiments carried out before the Second World War at the Geophysical Laboratory, Carnegie Institution, Washington, gypsum precipitates from a saturated solution of calcium sulphate in water at temperatures below 42°C., while anhydrite forms above that temperature. When sea-water evaporates at about 30°C., approximately one-half of the calcium sulphate present will be deposited as gypsum and only when the salt concentration has risen to about five times the normal for sea-water, does the remaining calcium sulphate precipitate as anhydrite. Thus if a deposit of anhydrite is assumed to have formed at less than 42°C., at least part of it must be secondary.

In the United Kingdom, both gypsum and anhydrite occur as primary minerals, and pseudomorphs of one mineral after the other are frequently found. Anhydrite is the common form at depth. Gypsification of anhydrite takes place when the latter lies near the surface through uplift and erosion, so that it is affected by ground-water circulation, and also at depth where the anhydrite is in contact with water-bearing strata. In general, therefore, although gypsum may be present locally to depths of nearly 1,200 m, workable deposits usually do not occur below a depth of 100 m or so and most of these are composed of secondary gypsum produced by the late hydration of anhydrite. Because of its slight solubility in water, gypsum generally outcrops only where there has been rapid erosion of the overlying strata or in arid regions.

There is no entirely satisfactory explanation for the origin of the thick beds of gypsum which have been recorded throughout the world. It has been calculated that if a 300 m column of sea-water were evaporated dry, about 0.3 m of gypsum would be deposited. The formation of thick beds would therefore require marine basins of considerable depth and to overcome the difficult quantitative problem several hypotheses have been put forward. One theory which supposes a basin separated from the open sea by a shallow bar allowing the entry of fresh supplies of sea-water, explains the formation of large deposits of mixed salts of marine origin but not of individual salts. A suggested modification is the existence of a series of connecting basins in which salts of differing solubility would be separately precipitated. Alternative mechanisms which have been suggested include the leaching of thin gypsum beds and their subsequent re-precipitation in deeper basins, the mechanical concentration by currents of already precipitated gypsum, and the solution of more soluble salts leaving only the relatively insoluble calcium sulphate in the rock.

Anhydrite, together with gypsum and limestone, forms the cap rock of many salt domes and plugs. It appears to be generally agreed that anhydrite in cap rock has been precipitated from groundwaters acting on the parent salt mass: gypsum is a product of anhydrite alteration. Anhydrite and gypsum, as well as halite and the carbonate minerals aragonite and dolomite, extensively underlie the modern supratidal salt flats or salt marshes ('sabkhas') stretching, for example, along the Trucial Coast in the southeastern part of the Arabian Gulf. Some workers regard the anhydrite in these deposits as a primary mineral, but there is evidence to suggest that most of the anhydrite has been formed by the replacement of primary gypsum. Some of the ancient evaporite sequences may have been deposited in environments comparable to the Trucial Coast.

Resources

Gypsum and anhydrite are widely distributed in England, principally in rocks of Permian and Triassic age (Fig 1) and, to a lesser extent, in Upper Jurassic strata. Anhydrite also occurs at depth within the Carboniferous Limestone, notably in Leicestershire. Commercial deposits are confined to the Upper Permian of Cumbria and North Yorkshire, the Keuper Marl of Nottinghamshire and Staffordshire and Jurassic strata in East Sussex. Anhydrite was mined in Cleveland on a large scale until 1971 and small gypsum operations were formerly active in Derbyshire, Leicestershire, Avon, Somerset and South Glamorgan. Thin beds and veins of gypsum occur widely throughout the Keuper Marl, for example, in the major depositional basins, the Cheshire Basin and the Somerset Basin. The mineral has been recorded also from Triassic sediments occurring between Annan and Canonbie, Dumfriesshire, Scotland. Gypsum or anhydrite is widely distributed in Northern Ireland in Permian and Triassic rocks, but not in commercial quantities.

Total resources of gypsum, although large, are much more limited than those of anhydrite because most gypsum deposits pass into anhydrite at relatively shallow depth. Resources of anhydrite in the United Kingdom probably amount to at least several thousand million tonnes, but the quantity of gypsum has not been estimated. The regional and stratigraphical distribution of gypsum and anhydrite are relatively well known and future gypsum workings are likely to be confined to those areas adjacent to existing operations. Deep borings in North Yorkshire for oil and gas have revealed large extensions to the anhydrite deposits of Cleveland and have shown that east of the Permian outcrop thick beds of anhydrite are present in the Zechstein Basin at various horizons and probably underlie much of North Yorkshire and Humberside.

Cumbria

East of the Lake District in the Vale of Eden, easterly dipping beds of gypsum and anhydrite occur within Upper Permian strata in the lower part of the Eden Shales along their western outcrop from Cotehill to Kirkby Thore (Fig 2).

There are four main gypsum/anhydrite beds ('A', 'B', 'C' and 'D') in the Kirkby Thore area (Fig 3), of which only the lower two, 'A' and 'B' beds, are being worked. The 'A' bed, which is largely confined to the Kirkby Thore area, consists of gypsum with mud and silt impurities and is up to 36 m thick, although normally only 9 m is mined.

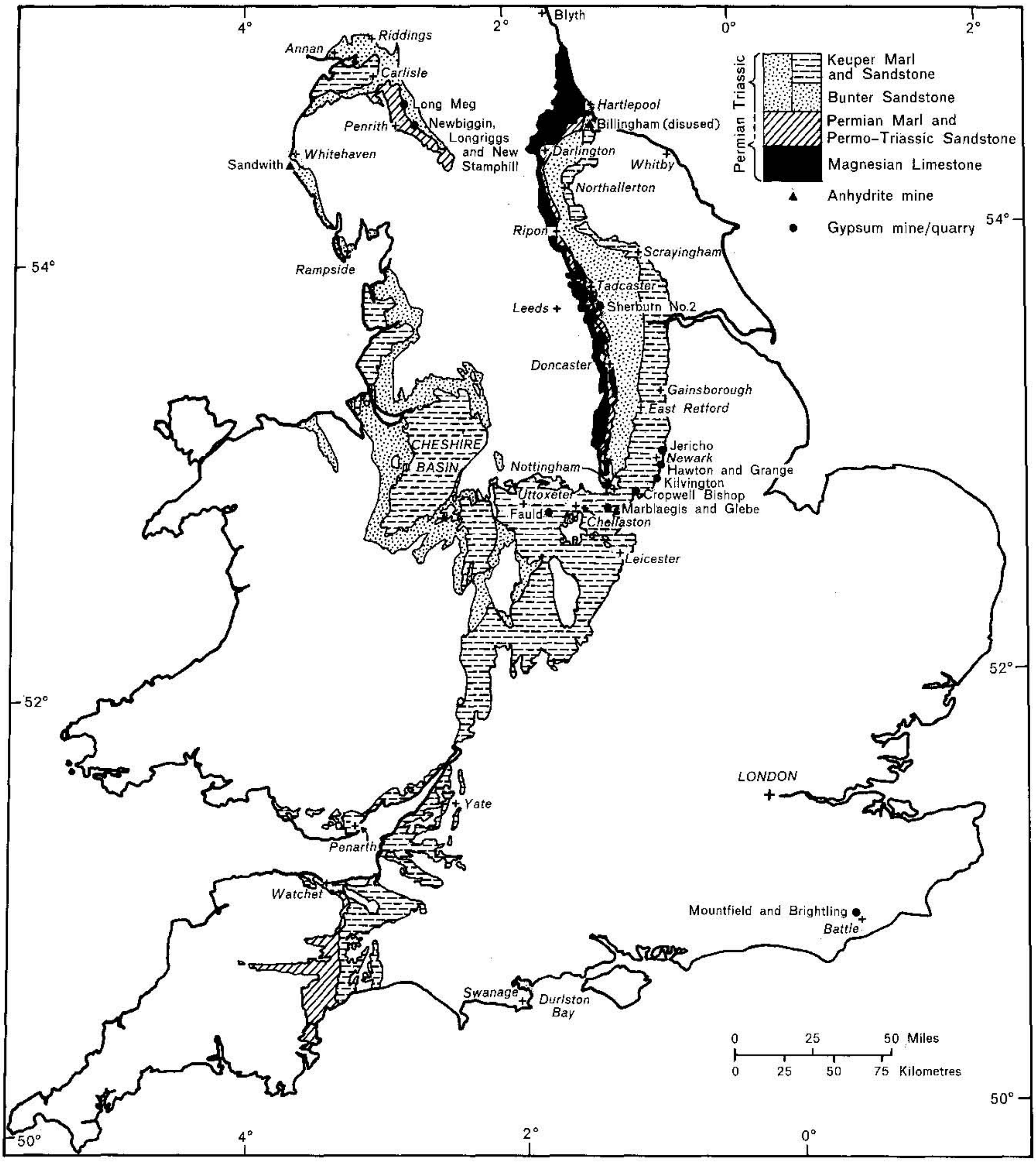

Fig 1 Distribution of Permian and Triassic rocks and the location of gypsum and anhydrite mines and quarries.

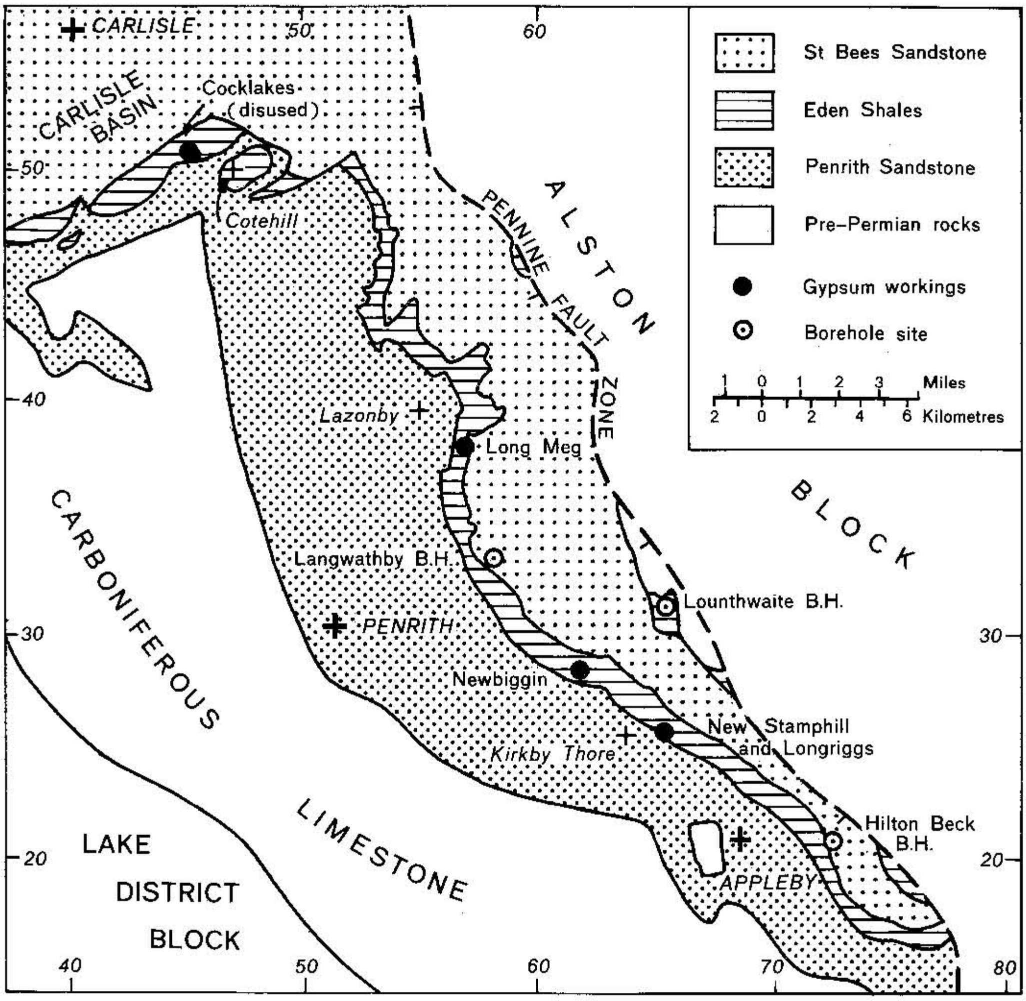

Fig 2 Location of gypsum workings in the Vale of Eden. (After R S Arthurton. *Rep. No.* 71/17, *Inst. geol. Sci.*, 1971, p. 2.)

The 'B' bed is the most persistent of the four evaporite beds, extending from Cotehill in the Carlisle Basin through the central part of the Vale of Eden at least as far southeastwards as the Hilton Beck borehole, east of Appleby. Anhydrite becomes more abundant with increasing depth. The bed is generally between 3 m and 6 m thick, but reaches its maximum recorded thickness of 6.6 m in the Institute of Geological Sciences' Lounthwaite borehole in the eastern outcrop of the Eden Shales. It is worked at Newbiggin, 11 km east of Penrith, and in the Lazonby area and was formerly exploited at Cocklakes and Knot Hill, near Cotehill, south-east of Carlisle. The Institute of Geological Sciences' Langwathby borehole, between Kirkby Thore and Lazonby, revealed a further bed of evaporite, known as the Langwathby bed, which is about 1 m thick, between the 'C' and 'D' beds. A gypsum deposit has been outlined recently at Kirkoswald which represents the northward continuation of the 'B' bed horizon at the Long Meg mine some 3 km to the south.

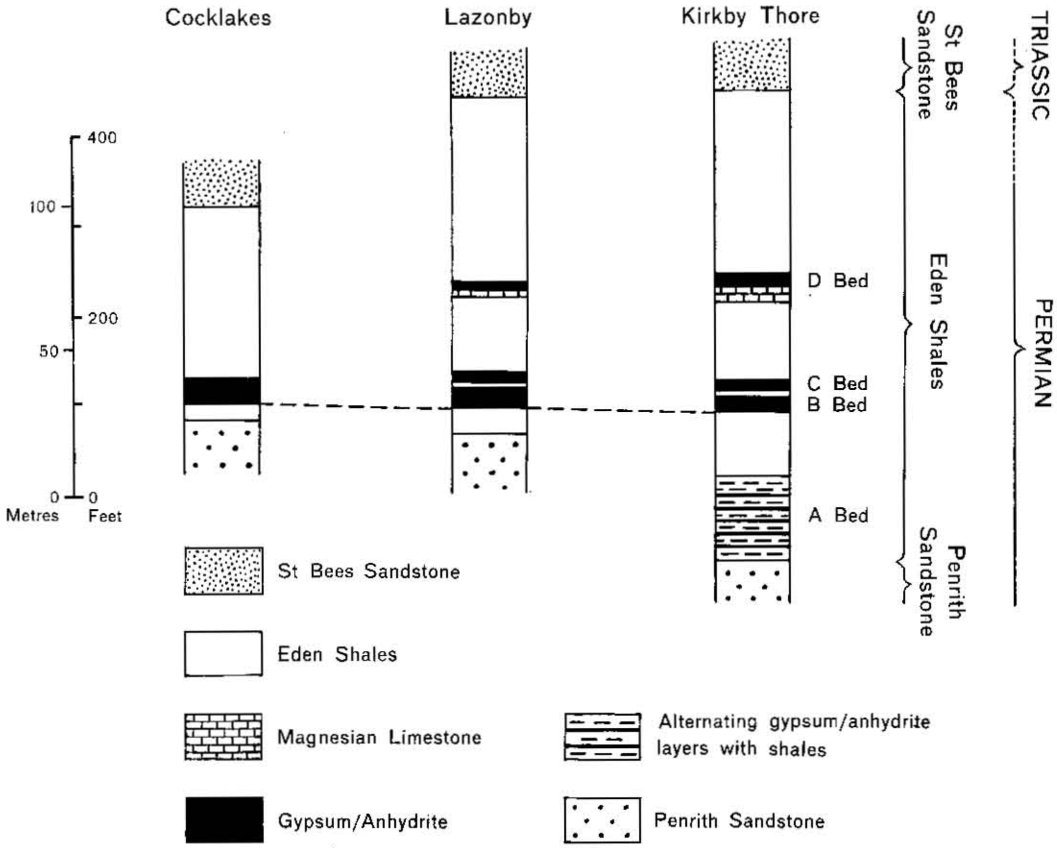

Fig 3 Generalised sections of the Permian and Triassic rocks in the Vale of Eden. (After H O A Meyer. *Proc. Yorks. geol. Soc.*, 1965, Vol. 35, Pt. 1, No.5, p. 73.)

In west Cumbria, between Whitehaven and Egremont, an evaporite succession consisting mainly of anhydrite, with some gypsum and dolomite, occurs at the base of the St. Bees Shales. The stratigraphy of the Permian succession in this area has recently been re-defined and it has been proposed that this carbonate-evaporite succession be considered as a separate formation, known as the St. Bees Evaporites (*see* Fig 4.). Gypsum was formerly worked at the Barrowmouth mine from adits driven into the cliffs at Saltom Bay, south of Whitehaven, but to the south-west, beneath St. Bees Head, the gypsum beds pass into anhydrite. Two main anhydrite beds are present in this area 3 m-5.5 m and 6 m-18 m thick, separated by 1.5 m-3 m of dolomitic marl. The anhydrite is mined at Sandwith where the workings extend down dip to depths of over 200 m below the surtace. A very similar evaporite succession is present at the base of the St. Bees Shales in south-west Cumbria. Thick beds of anhydrite with some gypsum have been recorded in a number of boreholes, in particular at Rampside, where an evaporite bed about 35 m thick was recorded at a depth of 467 m.

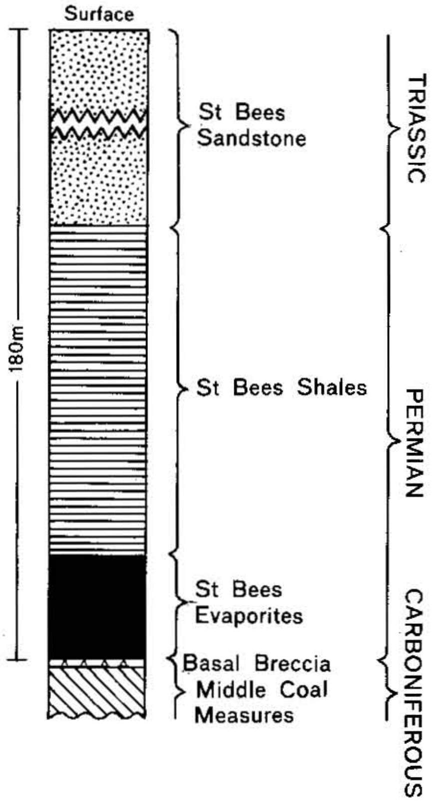

Fig 4 Proposed classification of the Permian strata beneath St. Bees Head (After R S Arthurton and J E Hemingway. *Proc. Yorks. geol. Soc.*, 1972, Vol. 38, Pt. 4, No. 24, p. 568.)

Eden Shales probably underlie the whole of the Carlisle Basin area beneath a thick cover of Triassic sediments. However, only thin gypsum and anhydrite beds have been recorded in the limited amount of drilling that has been undertaken. The most northerly occurrence known is at Riddings near the Scottish Border, where a borehole penetrated two thin gypsum and anhydrite beds.

Cleveland and Yorkshire

In the Upper Permian (Zechstein) strata of north-eastern England, anhydrite (and gypsum) occurs principally as the Upper Anhydrite, the Billingham Main Anhydrite and the Hartlepool Anhydrite formations (Fig 5). In the Hartlepool area the Hartlepool Anhydrite, which is 110 m thick under the town, was mined between 1925 and 1930, when the Billingham mine came into full production. Further to the south-east both the Upper and Billingham Main Anhydrite beds are present. The 6 m-9 m thick Billingham Main Anhydrite, above the Upper Magnesian Limestone was worked until 1971 at Billingham near Stockton at depths of 180 m to 300 m. The strata here dip towards the south-east and the anhydrite beds appear to thicken in this direction.

In the Whitby area, drilling for petroleum in 1939 and again in 1948-49 revealed several thick anhydrite beds associated with rock-salt and potassium-bearing minerals at depths of over 1,000 m. The Upper, Billingham Main and Hartlepool Anhydrite (known as the Hayton Anhydrite in North Yorkshire) formations are all present, together with a number of other anhydrite beds. In central North Yorkshire, gypsum and anhydrite occur in the Permian Upper Marls with smaller amounts in the Permian Middle Marls while in the

Doncaster – Selby – Goole area, coal borings have proved the Upper Anhydrite bed to be 4.5-6 m thick at depths of up to 450 m. Anhydrite occurs beneath most of North Yorkshire and Humberside at various stratigraphical horizons. The anhydrite (or gypsum) bed at the base of the Permian Middle Marls in North Yorkshire is believed to be equivalent to Hayton Anhydrite further east.

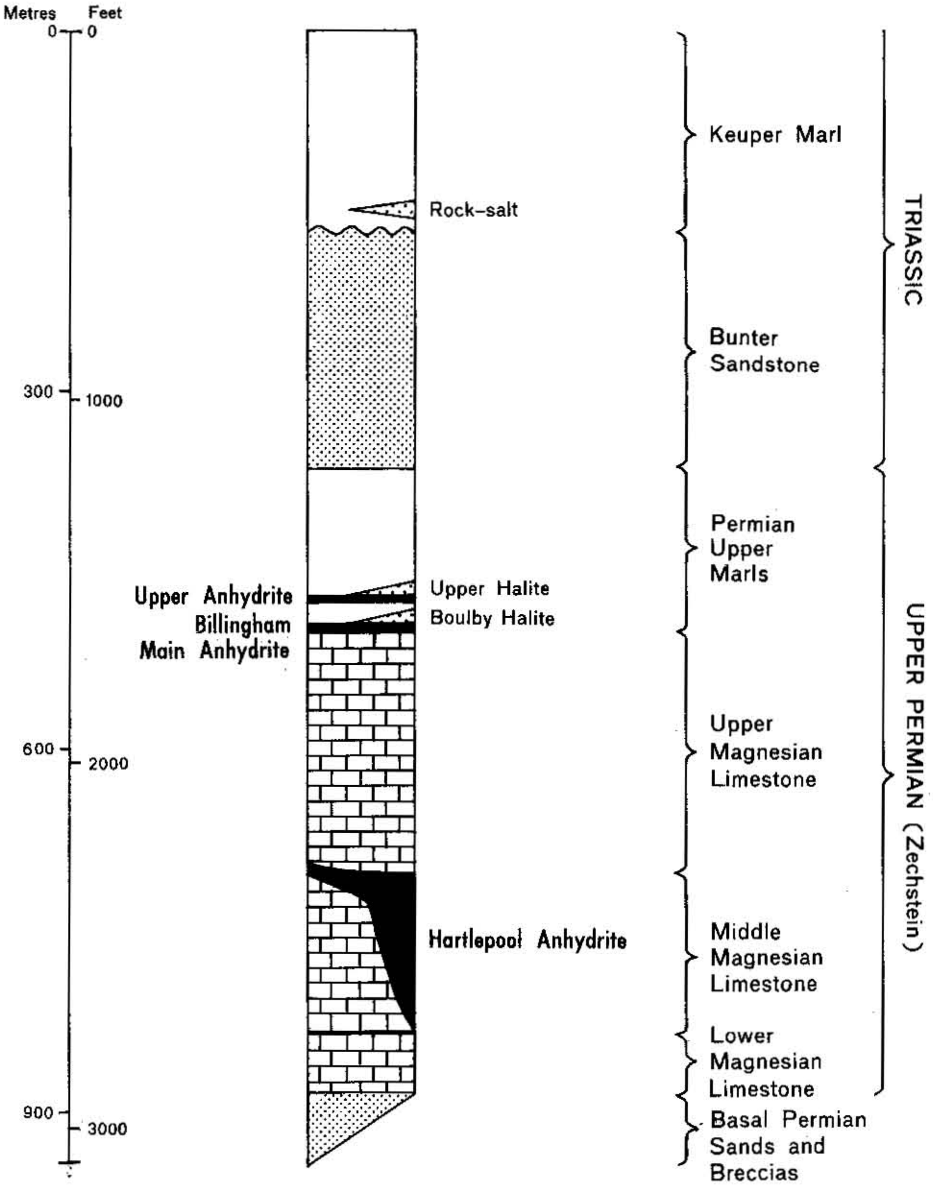

Fig 5 Generalised section of the Permian and Triassic rocks in the Billingham to Wilton area, Cleveland. (Based on B J Taylor, I C Burgess, D H Land, D A C Mills, D B Smith and P T Warren. *Br. reg. Geol.* 1971, p. 73.)

Much of the Permian and Triassic outcrop in North Yorkshire and Cleveland is masked by drift, but gypsum is thought to underlie much of the area. At Hurworth Place near Darlington an Institute of Geological Sciences' borehole drilled in 1972 revealed two beds of gypsum of commercial quality at depths of 45.36 m and 66.25 m. The upper bed, which is 7.63 m thick with a median bed of anhydrite 1.9 m thick, is the Billingham Main Anhydrite and the lower bed, 2.25 m thick, occurs at the base of the Permian Middle Marls and may be the Hartlepool Anhydrite. Further south a relatively thick bed of folded gypsum in the Permian Upper Marls, is exposed in the banks of River Ure, north of Ripon, and east of Leeds gypsum was formerly worked from the Permian Middle Marls at Ledsham and from the Permian Upper Marls at Hillam. A new mine has been developed at Sherburn-in-Elmet, 10 km south of Tadcaster, to work a 6 m gypsum bed (Upper Anhydrite) in the Permian Upper Marls some 12 m above the Upper Magnesian Limestone. Between Leeds and Doncaster gypsum has been obtained in the past from numerous pits scattered along the outcrop of the Permian Middle Marls and Permian Upper Marls, but southward into Nottinghamshire gypsum in Permian strata becomes less abundant.

The Newark Gypsum of the East Midlands thins north of Newark but may be traced as far north as Middlesborough, Cleveland, and has been worked locally in the past near Gainsborough, near Scrayingham, north-east of York, to the east of Northallerton, where relatively thick sequences of gypsiferous strata are recorded just below the Rhaetic Beds, and near Middlesborough.

East Midlands

In the East Midlands (Fig 6) thin beds, nodules and veins of gypsum are common in the Keuper Marl, but workable deposits are confined to two distinct zones near the top, known as the Tutbury Gypsum and the Newark Gypsum. A third zone, the East Bridgford Gypsum, in the Clarborough Beds lower in the Keuper Marl, has been worked in the past, mostly during the last century, although the beds of fibrous gypsum rarely exceed 0.2 m in thickness. At Clarborough, 4 km north-east of East Retford, a few hundred tonnes a year of gypsum were produced from the Clarborough Beds for agricultural purposes between 1947 and 1953.

The Tutbury Gypsum occurs in the Trent Basin about 43 m below the base of the Rhaetic beds and extends from east Nottinghamshire through southern Derbyshire, to Uttoxeter in Staffordshire. The bed is not continuous owing to post-depositional changes and now consists of lenticular masses, several metres in diameter and on average 2.5 m thick separated by gypsiferous marl.

Another bed about 2 m thick occurs 21 m above the main bed but as yet has not been exploited. The Tutbury Gypsum is mined at Fauld, near Tutbury in Staffordshire, and in the Gotham and East Leake districts of Nottinghamshire. There is a considerable difference in the quality of the Tutbury Gypsum worked in Staffordshire and Nottinghamshire, gypsum from the Fauld mine frequently having a much higher anhydrite content. The Fauld mine has long been famous for the production of alabaster and is now the only source of this material in the United Kingdom, although alabaster was formerly produced around Chellaston in Derbyshire, the Tutbury gypsum in this area averaging 2.5 m in thickness, but in places reaching 4.5 m.

The Newark Gypsum comprises up to 16 beds of gypsum from a few centimetres to 2 m in thickness separated by Keuper Marl mudstones about 1 m thick. The gypsum-bearing zone has a thickness of 15-18 m and occurs 7.5-18 m below the base of the Rhaetic Beds, immediately below the Tea Green Marls, where these are thin, but within them where these increase in thickness (as in

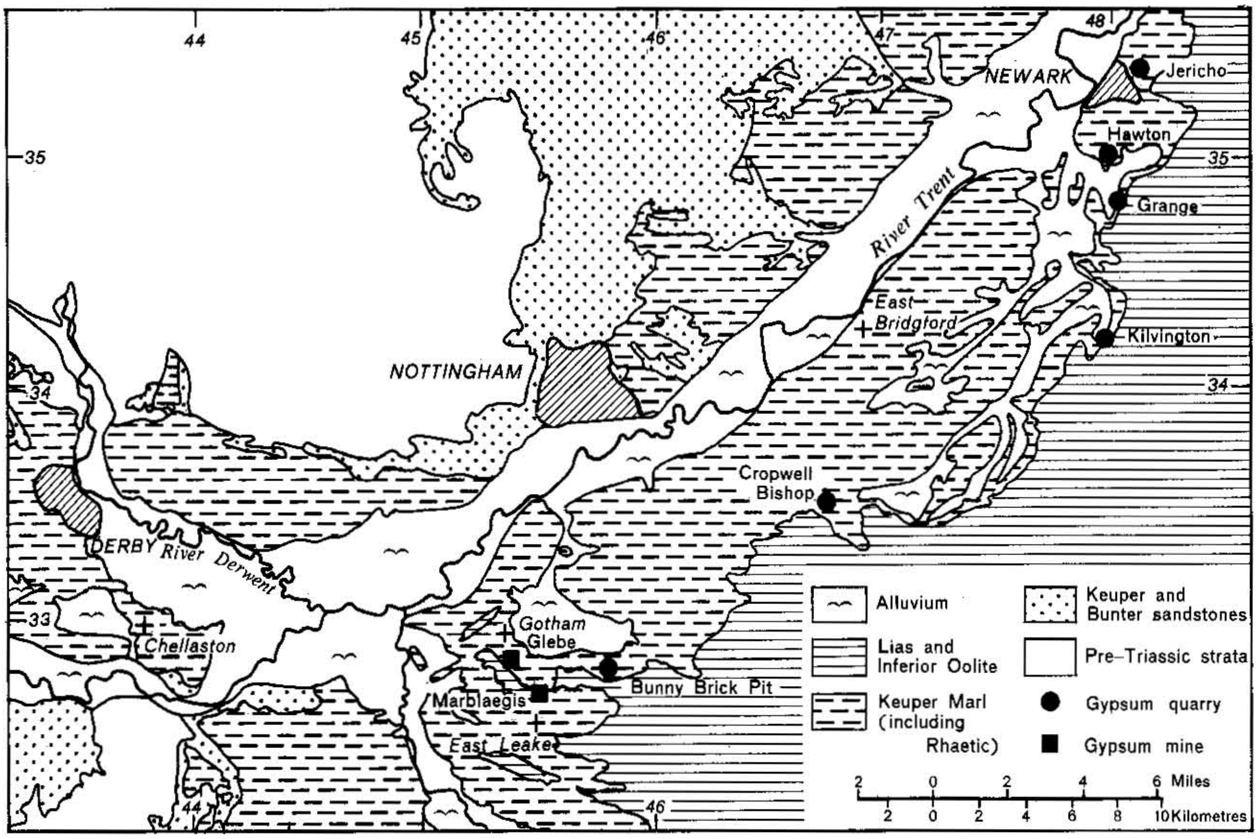

Fig 6 **Location of gypsum mines** and quarries **in the East Midlands.**

the south-west of England). Between Newark and Cropwell Bishop there is an overburden of 4.5-9 m and, unlike the Tutbury Gypsum, the Newark Gypsum is worked solely by opencast methods. The top two beds, which are of high quality, consist of lenticular masses of gypsum ('balls') up to 2 m thick and 4 m long. In the lower seams smaller masses ('cakes') vary from 0.5-1 m in diameter and 30-50 cm in thickness. It has been suggested that the Tutbury Gypsum passes laterally into the Newark Gypsum, the top bed of which is considered to be equivalent to the bed above the main Tutbury bed at Gotham and the lowest Newark beds equivalent to the main Tutbury bed.

South-East England

Gypsum deposits at the base of the Jurassic Purbeck Beds, immediately above the Portland Sandstone, are worked in a small area between Heathfield and Battle, north-west of Hastings, in inliers exposed along the crest of the Wealden Anticline.Four beds are present (Fig 7) in some 15 m of strata at depths of over 30 m; only No 4 seam is worked at the Mountfield mine and No 1 and No 4 seams at the nearby Brightling mine. The Purbeck evaporites are not restricted to the crest of the Wealden Anticline but, from the limited amount of borehole information available, appear to be fairly widespread over much of southern England from Dorset to the Weald, with anhydrite probably dominant below, say, about 250 m. The Institute of Geological Sciences' Fairlight borehole, about 24 km south-east of Mountfield, proved a greater thickness of evaporites than is present in the Sussex inliers; the 'Gypsiferous Series' was entered at 319.4 m and five evaporite beds were penetrated, with low-grade anhydrite predominating over gypsum. Gypsum also occurs in the Lower Purbeck Beds in Dorset and small quantities were formerly produced at Durlston Bay, near Swanage.

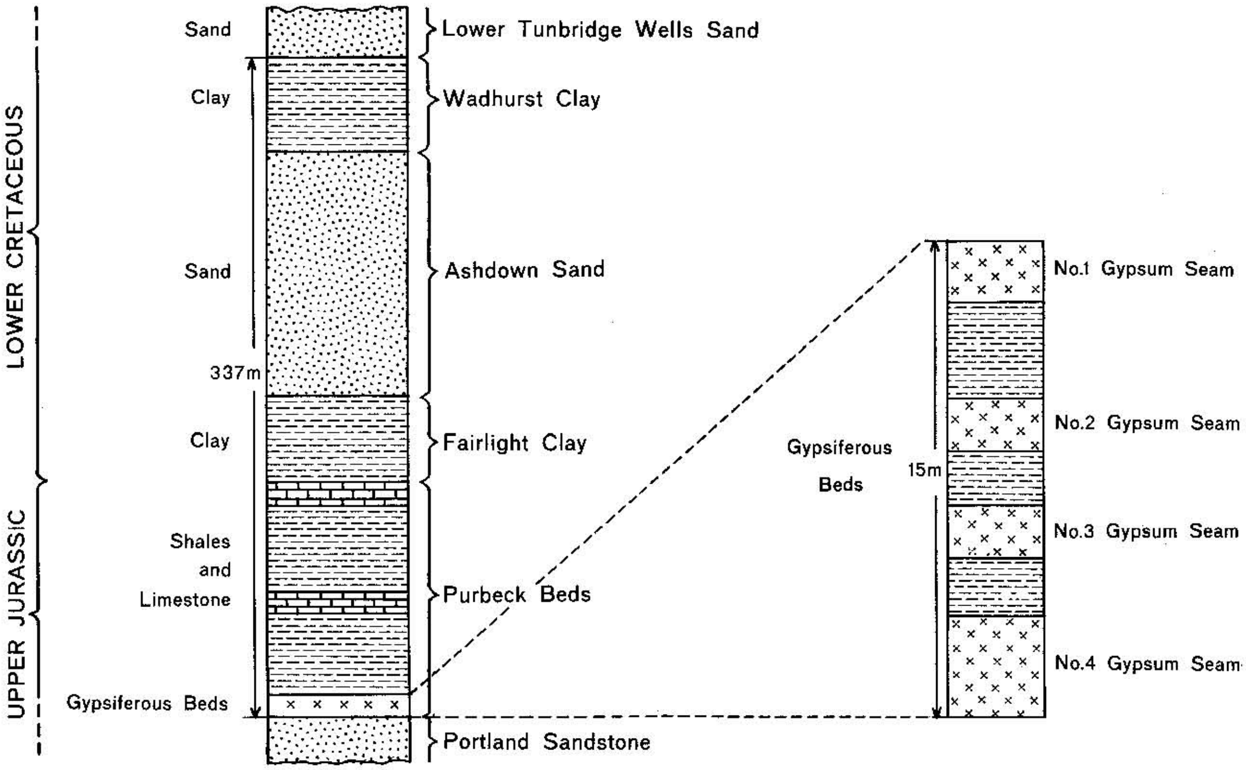

Fig 7 Generalised section of Upper Jurassic and Lower Cretaceous strata in the Mountfield area, Sussex. (After F Howitt. *Q. Jnl geol. Soc. Lond.*, 1964, Vol. 120, No.477, Pt. 1, p. 80.)

Wales

Appreciable amounts of gypsum occur in South Glamorgan, particularly in the area between Cardiff, Penarth and Barry, where thin nodular beds of gypsum, believed to be equivalent to the Newark Gypsum, are normally restricted to the uppermost 30 m or so of the Keuper Marl. Individual beds are not persistent laterally, however, and may degenerate sharply to minor streaks or isolated nodules. Nodular beds of gypsum or light pink alabaster exposed in a cliff section at and near Penarth have been widely used locally for ornamental purposes, chiefly in rock gardens. A bed situated between Penarth and Lavernock was worked to provide alabaster tiles for decorating the interior of the main building of the University College, at Cardiff.

Northern Ireland

Gypsum and anhydrite are widely distributed in Northern Ireland as veins, stringers and nodules in the Lagan Mudstone Group of Keuper Marl age. A significant thickness of bedded anhydrite has been proved only in the Upper Permian Marls in the Belfast area and other minor occurrences are recorded in Tyrone. Triassic sediments emerge from beneath the Chalk and the Antrim basalts and outcrop in the Roe Valley, from north of Cookstown to near Armagh in the south-west; along the Antrim Coast Road in the east; and in the Lagan Valley-Newtownards area in the south. Considerable thicknesses of Triassic sediment have also been proved in deep boreholes drilled by the Geological Survey of Northern Ireland, primarily in search of coal, at Magilligan, Portmore and Larne. Permian beds are preserved in small tracts at the Grange, County Tyrone, Cultra, on the southern shore of Belfast Lough and on the south-east side of the Newtownards trough. Some Permian sediments have also been proved in the Port More and Ballyalton boreholes. However, the only deposit of any significant thickness occurs at Avoniel, East Belfast City, where a bed of anhydrite about 5 m thick has been recorded at a depth of 111.2 m near the base of the Permian Upper Marls, (which are strongly gypsiferous at higher levels). The anhydrite is white to grey, massive, with small avoid crystals of anhydrite scattered throughout. There is a little sandy contamination in the basal 1 m. The only commercial production has been small quantities of gypsum formerly hand-picked from the Lagan Mudstone (Keuper Marl) in brickyards on the west side of Belfast. Anhydrite occurs at depth in Carboniferous rocks of the Clogher Valley, County Tyrone.

Other occurrences

Gypsum and anhydrite occur in other parts of England, but generally in minor amounts, although gypsum was formerly worked at a number of localities.

The Newark Gypsum extends southwards from the East Midlands through *Leicestershire* and into *Gloucestershire*, where it is associated with celestite at Yate north-east of Bristol, while in *Somerset* nodular masses of gypsum in impersistent beds were formerly worked from the cliffs at Watchet. Gypsum was formerly produced in Leicester as a by-product of Keuper Marl worked for brick-making.

Gypsum of Tutbury Gypsum age has been recorded also from near Stratford-upon-Avon in *Warwickshire.*

Anhydrite associated with the Carboniferous Limestone has been discovered in deep boreholes drilled in Leicestershire and west Cumbria. The Hathern Anhydrite Series in Leicestershire is by far the thickest, having been proved in a borehole 5.5 km north-north-east of Loughborough over an interval of 97 m at a depth of 538 m.

Continental Shelf

The anhydrite formations of west Cumbria and north-east England extend under the sea, and undersea extensions to the anhydrite workings of the Sandwith mine in west Cumbria have been proposed. Boreholes drilling by the National Coal Board have proved a thick bed of anhydrite off the coast of north-east England between Blyth and Hartlepool. In the north the anhydrite is less than 15 m thick but thickens gradually to the south, and off Hartlepool, the Hartlepool Anhydrite reaches a thickness of about 150 m, the top of the bed occurring at depths of about 180 m. Thick beds of Upper Permian (Zechstein) anhydrite have been discovered in the southern North Sea during the search for hydrocarbons.

Other resources

Sea water contains about 0.14 per cent by weight of calcium sulphate, compared with about 3.5 per cent total dissolved salts (mainly in the form of sodium chloride), and is a large potential source of calcium sulphate.

However, extraction is very unlikely while there are large reserves on land. Gypsum recovery is technically feasible as a by-product of the extraction of magnesia from sea-water and has been carried out in the United Kingdom on a pilot plant scale.

Calcium sulphate is produced as a waste by-product in the preparation of phosphoric and hydrofluoric acids. In view of the relatively large quantities of phosphoric acid produced in the United Kingdom each year, the waste represents an important potential source of gypsum and increasing interest is being taken in its commercial utilization (*see* pp. 31-32).

Land use

In the United Kingdom the total area covered by gypsum and anhydrite workings is not known precisely, but approximately 10,900 hectares are covered by planning permissions, excluding Cleveland, where anhydrite production has now ceased.

The major gypsum-producing county is Nottinghamshire, more than two-thirds of the total county output being extracted from the Marblaegis and Glebe mines. Planning permissions for gypsum extraction cover over 3,200 hectares and are almost entirely held by British Gypsum Limited and The Associated Portland Cement Manufacturers Limited. In 1971 it was estimated that of the 1,000 hectares covered by planning permissions for opencast workings,354 hectares remained to be worked. A similar survey carried out for underground workings in 1965 revealed that of the 2,200 hectares covered by planning consents,1,720 hectares still remained to be worked. Considerable areas still remain to be worked at the Fauld mine near Tutbury in Staffordshire, where planning permissions cover some 1,300 hectares, and in Cumbria, in the Vale of Eden and the Whitehaven district, over 3,600 hectares are covered by planning permissions. In Sussex some 2,400 hectares are covered by planning permissions in the neighbourhood of the Brightling and Mountfield mines.

Damage due to subsidence is not generally a major problem in the underground mining of gypsum and anhydrite. The panelled pillar and stall method of mining, whereby 25 per cent or more of the gypsum or anhydrite is left in the mine in the form of pillars to support the roof, has been used for more than 20 years. It is also usual practice to leave 0.5 m or so of seam in the roof and floor as an added precaution. This pillar and stall technique, with drivages at right angles to each other, is superior to the random pillaring method which used to be practised in some mines. Strict pillar symmetry is essential when mining anhydrite to avoid sudden failure of the pillars rather than gradual yielding. Some subsidence was reported at the Cocklakes mine in Cumbria, but this is thought to have been at an early stage in the operations before the pillar and stall system was properly established. The mine was closed in September 1966. Where two beds are worked in one mine, as for example at the Brightling mine in Sussex and the Sandwith mine in Cumbria, the pillars are superimposed to ensure stability.

Subsidence problems may, however, arise in the vicinity of some of the older gypsum mines. For example, large craters have been known to appear suddenly in the surface of the ground above worked-out galleries. The position and extent of recent workings are well known and documented, although with old workings, the precise extent may be unknown and even their presence may be unsuspected.

Sterilisation of reserves is not usually a serious problem as surface developments are not affected by the underground extraction of gypsum and anhydrite at depth. For example, the Billingham anhydrite mine extends at depths of over 245 m under residential and industrial areas. Sterilisation is a possible problem in the East Midlands where gypsum is quarried and mined at relatively shallow depths. Gypsum and anhydrite workings generally cover comparatively small surface areas and do not interfere, to any great extent, with other forms of land use. Underground workings are at comparatively shallow depths (45-180 m) and are entered by drifts, thereby avoiding the need for unsightly mine headgear. As the deposits which are considered to be economically workable have a low proportion of waste material there are no large tips or spoil banks. Where the mineral is extracted by opencast methods in agricultural country, backfilling and restoration follow the working face closely so that it is unnecessary for large areas to be withdrawn from cultivation at any one time. Apart from excavators and other equipment required for mining and quarrying there may be crushing, grinding and storing plant near a gypsum working and occasionally a plaster mill or plasterboard factory. It is desirable on economic grounds that the processing plant should be as close as possible to the workings.

A white coating of dust on the roofs of buildings and on trees and hedgerows surrounding crushing and grinding plant can occur at gypsum works, and dust precipitators are used which have an efficiency of about 95 per cent. Introduction of electrostatic precipitators is improving this performance. Gypsum dust is non-injurious to health and agriculture.

Present day opencast workings cause no dereliction as the land is restored in accordance with conditions contained in the planning permissions. The tipping of waste from underground mines causes no problems, as much of what is brought to the surface is disposed of as fill and road surface material. In Nottinghamshire what might be called 'semi-dereliction' over a few hundred hectares has been brought about by the older gypsum workings. Though the land has been 'restored' it is said to be of little or no use to agriculture as topsoil was not respread over the surface, mainly because of the lack of an adequate planning condition governing the retention of subsoil and topsoil for respreading on the back-filled material. However, additional restoration work undertaken by one company in recent years has resulted in the upgrading of some of this land.

Planning conditions governing the siting and landscaping of a gypsum mine or opencast working and the associated plant would not be expected to add much to the cost of the mineral. A notable exception is the Brightling mine opened in 1963 in a scenically attractive area of Sussex, where the local planning authority insisted that the aerial ropeway, which is 6 km long and connects the mine with the processing plants should be concealed wherever possible. As a result, considerable additional expense was incurred in providing for three angle stations and tunnels under public roads. The extra cost was around £170,000. The ropeway has a capacity of 150 tonnes per hour.

Uses and specifications

Gypsum

Gypsum has a wide variety of uses, by far the most important being in the manufacture of building plasters and plasterboard, and as a retarder in Portland cement, which accounted for some 97 per cent of the total production of gypsum in 1973.

The technique of plastering was introduced to this country by the Romans, but the material used was a lime plaster based on limestone which became the traditional plastering material. Gypsum plaster was introduced in 1254 and became well known as plaster of Paris with the development of the long-famous quarries at Montmartre. One of the earlier gypsum plastering contracts was for the renovation of Newgate prison. Even earlier is the use in England of gypsum in the form of alabaster, for example, in the Norman west doorway of Tutbury priory church built around 1160. The working of alabaster, principally in Derbyshire and Staffordshire, flourished in mediaeval times. English alabaster was much in demand at least as early as the end of the 14th century and is still used for sculpture and interior ornamental and decorative work and for making articles such as ash-trays and lampshades.

Calcined gypsum is used chiefly in the production of four types of building plasters; pre-mixed lightweight plaster, retarded hemihydrate plaster, anhydrous plaster and Keene's plaster (a variety of anhydrous plaster). Pre-mixed lightweight plasters, containing perlite or vermiculite as the lightweight aggregate, are the most widely used plasters today. In addition to their light weight they have the advantage of crack resistance, good thermal insulation, fire resistance and ease of application. Retarded hemihydrate plaster is mixed with sand for undercoat purposes but for finishing it may be used alone. Recent developments in plastering include a special projection plaster for machine application. Anhydrous plasters, for which there is a relatively small demand, are used to cover sand and cement undercoats, where a smoother, harder finish is required than is obtained with retarded hemihydrate plaster. Specialised plasters include pre-mixed gypsum plaster, with barytes ($BaSO_4$) as aggregate, for use as a radiation shielding material, and acoustic plasters with high sound absorption properties which contain pumice as a pre-mixed aggregate.

Large amounts of hemihydrate gypsum plaster are used in the production of plasterboard, of which there are four basic types; wallboard, baseboard, plank and lath, differentiated by their size and the type of paper lining used. There are four related products; plastic faced plasterboard, dry cellular core partition panels, plasterboard cove and laminated plasterboard with a veneer of aluminium foil (to improve thermal insulation) and PVC (to provide a decorative finish).

Gypsum plaster is also used for fireproofing and lagging; as a moulding and casting plaster for the pottery industry; for bedding plate glass during the grinding and polishing stages; in the preparation of dental and surgical plasters; for a variety of casting purposes in the electrical, engineering and foundry industries; in the moulds for making tyres; for stemming shotholes in quarrying and mining and for various sealing and fireproofing applications in coal mining. Small quantities of hemihydrate plaster (plaster of Paris) are also used for moulding purposes in modelling and sculpture work.

Large quantities of crushed uncalcined gypsum are mixed with cement clinker and subsequently finely ground to produce Portland cement, additions of between 4 and 8 per cent normally being required to control and retard the setting time of concrete and mortar. It is estimated that of the total gypsum output in 1973 approximately 35 per cent was used in plaster, 27 per cent in cement, 35 per cent in plasterboard and 3 per cent for other uses.

Ground gypsum is used as a fertiliser to make good calcium and sulphur deficiencies in the soil, and as a conditioner to reduce soil salinity. Less than 1 per cent of the total gypsum produced is used for agricultural purposes and 70 per cent of this is employed in mushroom farming. Ground gypsum, known as mineral white or terra alba, is used chiefly as a filler in paint and paper manufacture and as a diluent or carrier in insecticidal dusts. Gypsum is also used for 'burtonising' or artificially introducing permanent hardness to water used in brewing beer. Gypsum is also used in oil well drilling muds to increase the calcium ion concentration causing flocculation of the clay minerals and thereby thinning the mud.

Anhydrite

The main uses of anhydrite in the United Kingdom have been in the manufacture of sulphuric acid (and cement clinker) and the fertiliser ammonium sulphate. In view of the increasing use of high-analysis fertilisers, there is no longer a significant demand for ammonium sulphate in the United Kingdom and the only plant producing this fertiliser from anhydrite, at Billingham in Cleveland, closed in April 1971.

Small quantities of anhydrite are used as a refining agent in the manufacture of bottle glass; anhydrite was formerly used in the preparation of certain plasters and, until 1971, in the production of supersulphated cement. It has been used on a substantial scale since 1969 in Federal Germany for gateside packing in coal mines. A mixture of granular and powdered anhydrite into which water and an accelerator have been injected provides, on setting, a support for the strata alongside gate roadways. This application is being tested in a colliery in Durham and is potentially a large market for anhydrite in the United Kingdom.

Specifications

There are no precise specifications for either gypsum or anhydrite, but the trade recognises several impurities or contaminants which are detrimental for certain uses. Gypsum produced in the United Kingdom varies considerably in quality, the chief impurities present being mudstone, shale, anhydrite, dolomite and limestone, as well as small amounts of iron oxides, silica and sodium chloride. The highest quality rock, which is obtained from the top beds of the Newark Gypsum, has a good white colour, is free of contaminating mudstone and may contain more than 99 per cent $CaSO_4.2H_2O$. Such high-grade gypsum is used in the manufacture of barium plasters, plaster of Paris for specialised moulding purposes, surgical and medical plasters, as a filler in paint and in the brewing of beer. Lower-grade gypsum, containing more than 90 per cent $CaSO_4.2H_2O$, is used as a moulding plaster in the pottery industry. Apart from the Newark Gypsum, the beds worked contain from 95 per cent $CaSO_4.2H_2O$, as at the Sherburn No 2 mine in North Yorkshire, to about 78 per cent $CaSO_4.2H_2O$ in the Sussex mines.

The lower grades, which account for most of the gypsum produced in the United Kingdom, are suitable for the manufacture of wall plasters and plasterboard, Portland cement and for use as a soil conditioner. For plaster and plasterboard manufacture soluble salts, ie sulphates and chlorides of sodium, potassium and magnesium, should not exceed 0.2 per cent by weight as they give rise to efflorescence. The presence of anhydrite tends to lower the strength of wall plasters. A minimum of 92 per cent $CaSO_4$ is generally required for anhydrite used in sulphuric acid manufacture. The principal impurities are calcium carbonate, magnesium carbonate, iron oxide, sodium chloride and occasional inclusions of sandstone.

The following British Standard specifications relate to the quality of gypsum plaster and plasterboard: B.S. 1191, Part 1: 1973. 'Gypsum Building Plasters. Excluding premixed lightweight plasters'. Part 2: 1973, 'Gypsum Building Plasters. Premixed lightweight plasters'; B.S. 1230 Part 2: 1970. 'Gypsum Plasterboard'.

Price

Prices for gypsum and anhydrite are not generally available, as both minerals are largely used captively. However, the monthly journal 'Industrial Minerals' publishes a price for gypsum, crude, (as used by the cement industry) ex-mine or c.i.f., which in October, 1974, was quoted at £1.75–£2.25 per long ton (£1.72–£2.21 per tonne). The average c.i.f. price of raw gypsum imported from the Irish Republic and France in 1973 was £2.49 per tonne and £4.08 per tonne respectively. The price of ground gypsum in November, 1974, varied from £7.50 to £16 per tonne, ex-works, depending on grade.

Technology

Gypsum is mined both underground and opencast, whereas anhydrite is produced solely by underground mining. Underground access is by adits or drifts and conventional pillar-and-stall mining techniques are employed. In general, neither gypsum nor anhydrite undergo any form of processing other than screening, crushing and grinding prior to use.

Mining

Beds of gypsum or anhydrite worked in the United Kingdom range from 1.8 m to 4.5 m in thickness. At underground mines extraction rates of 60 to 75 per cent are achieved. After blasting, the mineral is usually loaded and transported by trackless mining equipment, notably load-haul-dump 'scoop-trams', to underground primary and secondary crushers, and is transferred to the surface by conveyor belt. A novel method of loading, which was devised and introduced at the Long Meg mine in Cumbria in 1959, is a tractor-tipping trailer fitted with a winch and scraper bucket.

At the Mountfield mine in Sussex approximately 1.5 m of calcareous sandstone at the top of the Portland Sandstone is also removed. The limestone, which is one of the very few indigenous sources in south-east England of hard rock suitable for aggregate, is mined separately after the gypsum has been extracted, although the same crushing and conveying equipment is used. The sandstone is crushed, screened and sold as coated aggregate for roadstone. In the neighbouring Brightling mine methane gas can occur in significant concentrations from time to time, so that the regulations controlling the operations are more complicated than those usually associated with gypsum mining in the United Kingdom. Methane may also occur in the Sandwith anhydrite mine near Whitehaven. A continuous mining method is employed experimentally at the Sherburn No 2 mine in North Yorkshire. Gypsum (or anhydrite) from the working faces is regularly sampled and blending is undertaken where necessary to maintain a consistent feed for the processing plants.

Gypsum is worked by opencast methods in the East Midlands south of Newark and near Kirkby Thore in Cumbria. The Newark Gypsum is entirely worked in this way, the overburden, 4.5-9 m thick, being stripped to the top bed by tractor-scrapers. The gypsum and interbedded mudstones are loosened by blasting prior to removal by dragline excavators. Up to twelve beds from a few centimetres to 2 m in thickness are worked. At the Newbiggin quarry, Kirkby Thore, up to a maximum of 18 m of overburden is removed to recover on average some 6 m of gypsum.

Blocks of alabaster are produced at the Fauld mine in Staffordshire by cutting or shearing a rectangular outline in the working face followed by removing the portion of roof above it and drilling a series of holes along what will be the other face. By this means, blocks weighing from 1 to 6, but sometimes as much as 20 tonnes can be obtained. The blocks are brought to the surface on rail cars. At the Sandwith mine on the Cumbrian coast, two anhydrite beds each with an average worked thickness of 4.5 m, separated by 3 m of dolomitic marl, are mined at a depth of about 180 m. Rooms 8.5 m wide and 4.3-5.5 m high are driven at 18 m centres leaving 9.75 m square pillars and permitting an extraction rate of 72 per cent. The anhydrite mined contains an average of 92 per cent $CaSO_4$. Shale (St. Bees Shale), for use in the sulphuric acid process, is now also mined underground and has the advantage of containing a small proportion of $CaSO_4$ mainly as thin beds of gypsum. Percussion drilling and high-velocity explosives, are used to break up the hard, brittle anhydrite prior to loading and transportation to automated crushers, which reduce the anhydrite and shale to -50 mm size. A belt conveyor carries the anhydrite to the surface at the rate of up to 450 tonnes an hour. Blending of the anhydrite and shale in the ratio of 4:1 is carried out underground, although further mixing is undertaken at the surface to ensure a uniform and consistent feed to the kilns A bed of anhydrite some 7.4 m thick was formerly worked by similar methods at Billingham in Cleveland.

Processing

Gypsum is generally only screened to remove fines (mainly mudstone and shale), crushed and ground, but at the Robertsbridge works in Sussex and the Fauld works near Tutbury in Staffordshire, heavy medium separation is used to remove such impurities as shale, dolomite and anhydrite (Fig 8). At Robertsbridge the -150 + 100 mm fraction, which does not require beneficiation, is screened off and by-passes the heavy media separation plant for use in the production of anhydrous gypsum plaster. In the heavy media plant the rock is dry and wet screened at 10 mm, the +10 mm material passing into a drum separator, which operates on an aqueous medium containing 60 per cent magnetite and 40 per cent ferrosilicon giving a specific gravity of about 2.46. Media consumption is about 230 g/t. The gypsum float is then transferred by conveyor belt to the secondary crusher and finally reduced to a fine powder in grinding mills prior to calcination. The sink product, which represents about 20 per cent of the mine output, consists of dolomite, shale and anhydrite and is sold either as hard core or, after crushing to -40 mm size, as a fill for roadway construction. The -40 mm rejects may be reprocessed separately through the heavy media separation plant at a specific gravity of 2.60 to produce more gypsum float and a dolomite by-product. The dolomite which is recovered in this way occurs as a bed about 0.3 m thick within the No 4 Gypsum Seam and is sold as coated roadstone. The bed worked at Fauld has a relatively high anhydrite content, which is removed by heavy medium separation.

At the Cropwell Bishop quarry in the East Midlands photo-electric colour sorting machines are used to up-grade second grade gypsum to conserve reserves of higher quality material. The rock is crushed to approximately 6.5 mm to 19 mm particle size and fed by conveyor belt into an optical box. Each particle is inspected by photo-electric cells and its degree of whiteness registered. If the colour and therefore the quality due to contaminating mudstone falls below the required standard, the particle is blown off its intended course into the rejects bin. Electrostatic separation is used to beneficiate finer particle sizes.

In the manufacture of hemihydrate *gypsum plaster* ($CaSO_4.\frac{1}{2}H_2O$) gypsum powder is calcined at temperatures of between 150°-$165^\circ C$ to drive off about three-quarters of the combined water. Calcination is undertaken in large kettles, circular open pans, rotary kilns or in an autoclave, the kettle system being by far the most widely adopted. Finely ground gypsum is fed into kettles or large cylindrical steel shells, which range from 2.4 to 4.6 m

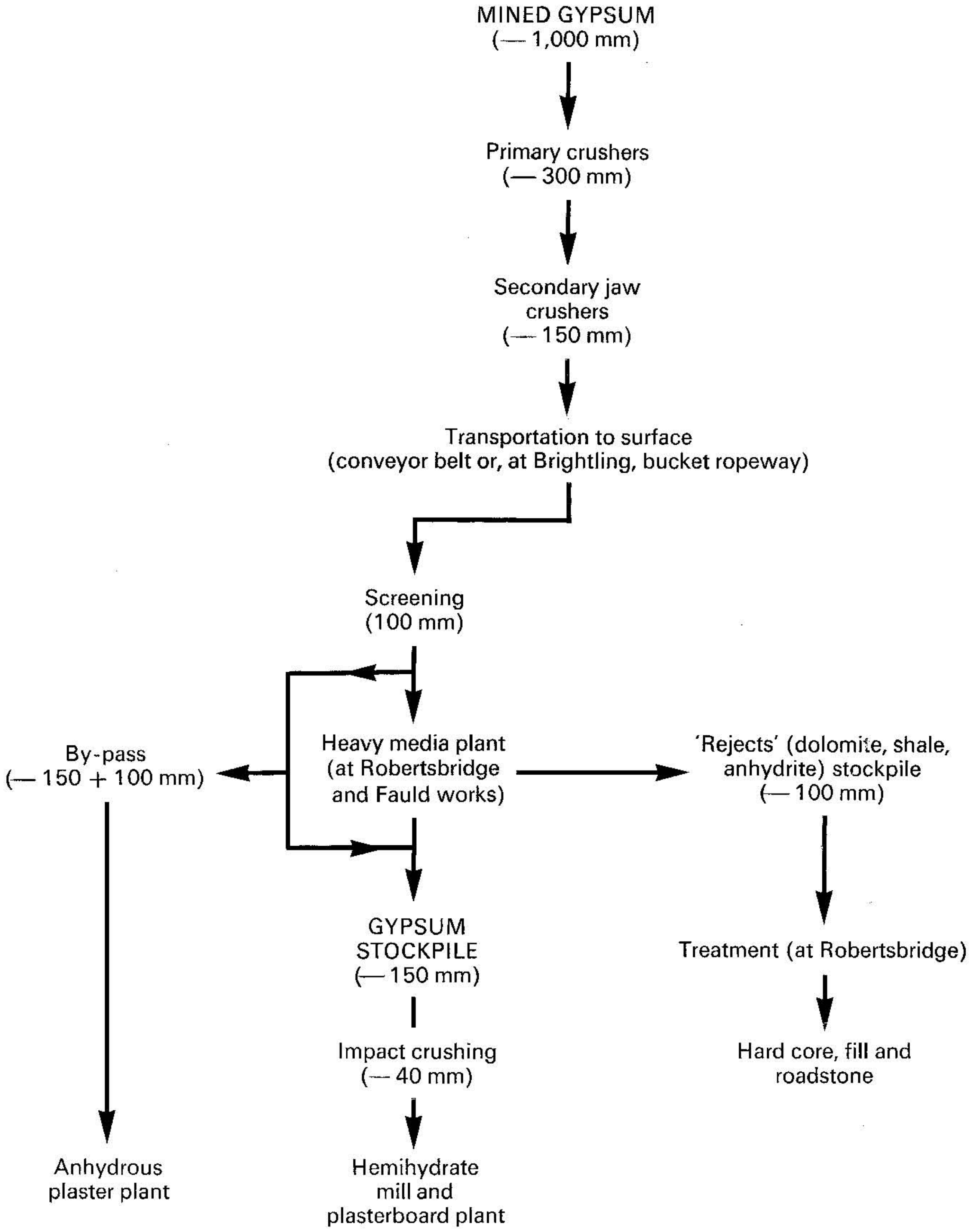

Fig 8 Simplified flow diagram of gypsum processing and handling.

in diameter, 1.8 m to 4.3 m in depth, and most commonly have a capacity of 12-16 tonnes. The kettles are either coal, oil or gas fired and the gypsum is heated by circulating hot gases around the pot and through horizontal flues extending through the pot: the gypsum is constantly agitated by horizontal rabble arms to prevent overheating. The time of calcination, which depends on the firing rate, is usually between 2 and 3 hours. After calcination the resultant hemihydrate, which contains 5 to 6 per cent water and is largely in the β form, is discharged through the base of the kettle and is subsequently reground.

The open pan process was for many years the traditional English method of calcining and is still used to a limited extent. Ground gypsum is fed into flat bottomed circular pans 5.5 to 6.7 m in diameter, to a depth of about 15 cm. The pans are coal fired and the gypsum is stirred by heavy chains dragged along the bottom of the pan to distribute the heat evenly. β-hemihydrate is the main product of pan calcination. α-hemihydrate plasters are produced in an autoclave by calcination under steam pressure. Hemihydrate gypsum plaster sets too quickly for most plastering operations and chemical retarders are added to delay and control the setting time. The mixing of chemical additives and lightweight aggregates is automatically controlled. In the production of anhydrous plasters, the water content is further reduced to 1.5 per cent (compared with around 5 per cent in hemihydrate) by calcining lump gypsum in the presence of potassium sulphate in coal fired kilns at a temperature of 600°C. As these plasters have a slow setting time, such chemicals as potassium sulphate and alum are introduced to accelerate setting to a workable time of usually 1 to 4 hours.

At Fauld, anhydrous plaster is manufactured by a rotary kiln method, by which raw gypsum crushed to -25 mm is calcined at temperatures of between 800°C and 900°C., in a rotary kiln somewhat similar to that used in Portland cement manufacture. After discharge the calcined product is reduced to a fine powder in a ball mill. The various grades of plaster are automatically packed in 50 kg bags for delivery.

In the manufacture of *plasterboard,* hemihydrate plaster is mixed with water to produce a plaster slurry, which is then encased in durable paper liners and the continuous plasterboard sandwich is cut to the required length before it passes through a kiln to remove excess water. Further sizing and grinding of the edges of the board is carried out to conform with specifications before the plasterboard is delivered. Plasterboard was first produced in the United Kingdom in quantity in 1917 at Wallasey, Cheshire.

Anhydrite

Anhydrite has been used continuously in the United Kingdom since 1923, in the manufacture of both sulphuric acid (and cement clinker) and, until 1971, the fertiliser ammonium sulphate. Gypsum may also be used in these processes but more fuel is then required to eliminate the water of crystallisation it contains. The process which is in commercial use in the United Kingdom is the production of sulphuric acid and cement clinker by calcination (the Müller-Kühne process), while ammonium sulphate was formerly produced from anhydrite by double decomposition. These processes are based essentially on pioneer development work carried out in Germany by the Bayer group at Leverkusen during the First World War and subsequently continued by Imperial Chemical Industries Limited.

The Müller-Kühne process consists of roasting ground anhydrite, clay or shale, sand and coke to a temperature of between 1200° and 1400°C, in rotary kilns, the calcium sulphate being reduced to lime which combines with the shale to form cement clinker. Gases containing up to about 9 per cent sulphur dioxide are produced which are passed through a cyclone to collect dust and through an elaborate purification system before being converted to sulphuric acid. An important feature of the process is that about 0.95 tonne of cement clinker is produced with every tonne of acid from 1.7 tonnes of anhydrite. The reaction can be expressed empirically as follows:

$$2CaSO_4 + C \rightarrow 2CaO + 2SO_2 + CO_2$$

In the double decomposition or Merseburg process, ammonia and carbon dioxide are passed into a slurry of finely ground anhydrite or gypsum to form ammonium carbonate, which reacts with calcium sulphate to give calcium carbonate and ammonium sulphate; the latter dissolving in water. The reaction can be expressed as follows:

$$CaSO_4 + (NH_4)_2CO_3 \rightarrow CaCO_3 + (NH_4)_2SO_4$$

The ammonium sulphate solution is filtered off and concentrated in evaporators to crystallise out the ammonium sulphate. Ammonium sulphate is used chiefly as a fertiliser, while the calcium carbonate may be used in the manufacture of cement and the fertiliser calcium ammonium nitrate. Gypsum or anhydrite may also be reduced to calcium sulphide from which H_2S is produced and converted to sulphur, or, with carbon monoxide, to sulphur dioxide and lime, but these processes are not in commercial use.

Research

At a large central research department set up in 1956 at East Leake in Nottinghamshire, BPB Industries (Research and Development) Limited carries out investigations for all companies in the BPB Group including British Gypsum Limited, both at home and overseas. Work carried out in the gypsum field includes the development of improved and novel plasters, improved forms of plasterboard and their application to ceilings, lining and partitions. Facilities include fire testing equipment, acoustic laboratories, and equipment such as the stereoscan for crystal studies. Pilot plant is available for studying and developing production processes and a service is provided to production units for plant and quality optimisation. The study of methods for beneficiating low-quality gypsum, such as heavy medium separation, colour sorting and electrostatic separation is another important project. Developments for non-building use, in collaboration with the National Coal Board have included 'Hardstop' for explosion-proof stopping and cavity fillings, and 'Anpak', an anhydrite-based product for gateside packing in coal mines. Products have also been developed for agricultural and horticultural use.

BPB Industries Limited has carried out a considerable amount of research, particularly in the field of geophysics, into new methods of delineating gypsum deposits and assessing mineral quality. Important new developments include borehole logging using resistivity, radiation and density techniques, for the *in situ* determination of the gypsum, anhydrite and mudstone contents of evaporite deposits.

The Building Research Establishment has developed a glass fibre-reinforced gypsum plaster for the manufacture of components of high impact strength and fire resistance. This development is patented and has been licenced by the National Research Development Corporation to a number of firms in the United Kingdom. Investigations carried out by the National Radiological Protection Board in collaboration with the Building Research Establishment have led the Board to conclude in June, 1972, that phosphogypsum may safely be used for plaster and plasterboard provided the concentration of radium (the principal source of radioactivity in phosphogypsum) in the finished products is limited to about 25 picocuries per gramme and the production is recorded so that the Board can periodically assess the population dose. Discussions on this subject have since been held between the Board, the Department of the Environment and the Department of Industry. Flexible gypsum plasters, produced by adding natural latex to gypsum plaster, have been developed by the Malaysian Rubber Producers' Research Association.

Cement clinker containing 1.2 per cent P_2O_5 has been produced on a pilot-plant scale by the Building Research Establishment as a co-product with sulphuric acid from phosphogypsum obtained from Whitehaven. The phosphogypsum had to be reslurried and washed before it could be successfully used, which would increase costs and also raise a number of operational difficulties. Tests have also been conducted on the use of by-product anhydrite from hydrofluoric acid manufacture, but the cement produced was apparently of very low quality. Waste anhydrite may be used in the continuous process developed by Imperial Chemical Industries Limited to produce α-hemihydrate, but the anhydrite must first be converted to 80 to 90 per cent gypsum.

Production

The United Kingdom is largely self-sufficient in both gypsum and anhydrite, in 1973 ranking sixth among the major producing countries (Table 1), and for many years was the principal world producer of anhydrite. Combined production of these minerals amounted to some 4.2 million tonnes in 1973, of which 3.8 million tonnes was gypsum and 0.4 million tonnes anhydrite. Approximately 127 million tonnes of gypsum and anhydrite have been produced in the United Kingdom during the period 1873-1973 (Fig 9 and Table 2).

Table 1 World production of gypsum and anhydrite, 1970-1973, by major producing countries

Producing Country	*Thousand tonnes*			
	1970	*1971*	*1972*	*1973*
USA	8,561	9,451	11,184	12,428
Canada (*a*)	5,732	6,080	7,348	7,544
France (*a*)	6,210	5,112	6,192	6,159
USSR (*b*)	4,700	4,700	4,700	4,700
Spain (*a*) (*b*)	4,000	4,200	4,200	4,200
United Kingdom (*a*)	4,275	4,173	4,164	4,208
Italy (*b*)	3,266	3,500	3,500	3,629
Federal Germany (*a*)	2,028	2,534	2,683	2,948
World total (*b*)	50,000	52,000	57,000	58,000

(*a*) Including anhydrite (*b*) Estimated

Source: Institute of Geological Sciences.

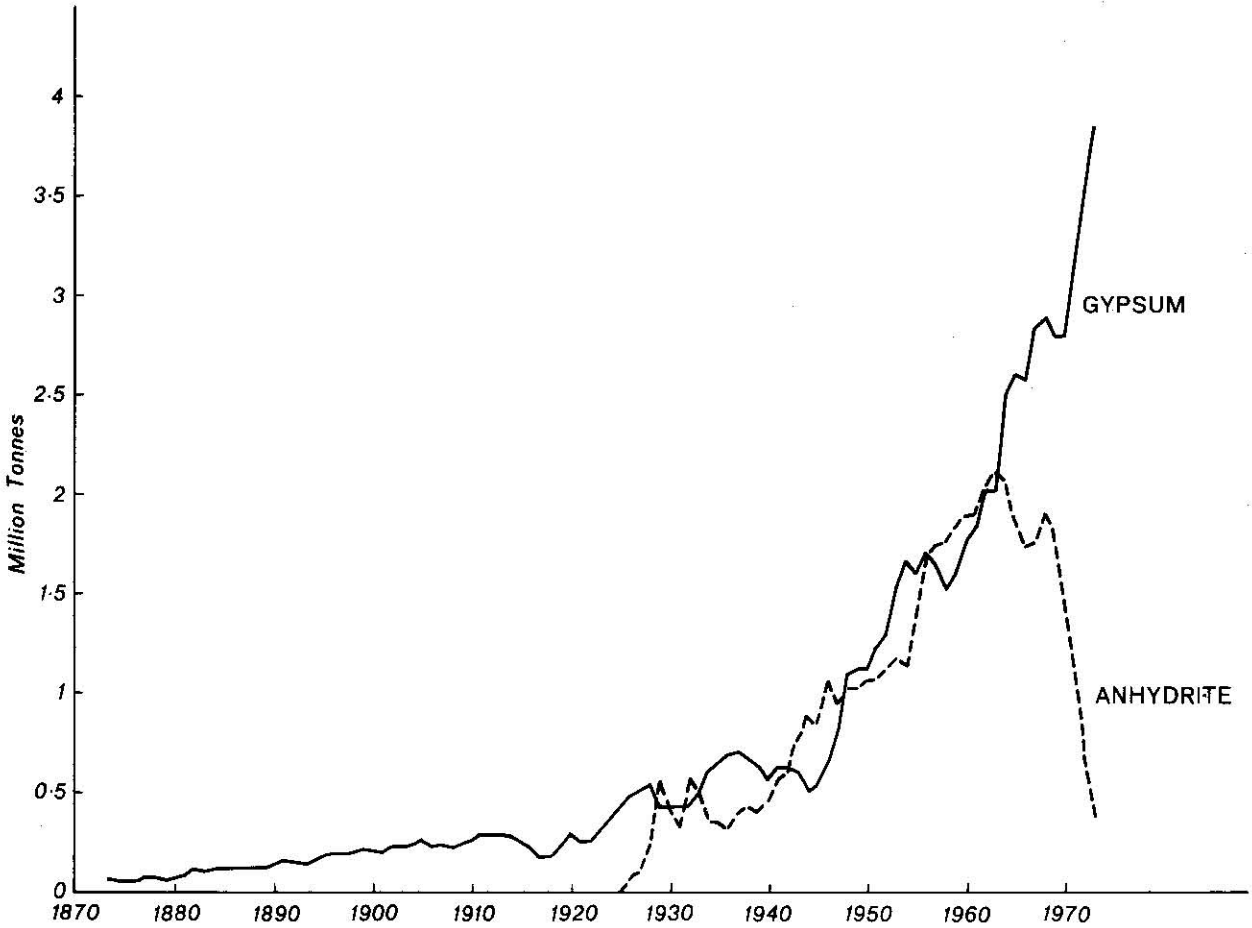

Fig 9 Production of gypsum and anhydrite in the United Kingdom, 1873-1973.

Table 2 United Kingdom: Production of gypsum and anhydrite, 1873-1973

Thousand Tonnes

	Gypsum		*Gypsum*		*Gypsum*
1873	67	1888	132	1902	228
1874	62	1889	135	1903	223
1875	66			1904	238
1876	63	1890	143	1905	260
1877	75	1891	154	1906	229
1878	76	1892	150	1907	239
1879	63	1893	146	1908	232
		1894	156	1909	243
1880	77	1895	181		
1881	81	1896	196	1910	260
1882	104	1897	184	1911	281
1883	101	1898	199	1912	290
1884	111	1899	216	1913	290
1885	114			1914	270
1886	121	1900	211	1915	251
1887	123	1901	204	1916	223

Table 2 (Contd.)

Thousand Tonnes

	Gypsum	*Anhydrite*
1917	176	–
1918	182	–
1919	224	–
1920	292	–
1921	269	–
1922	262	–
1923	323	–
1924	378	–
1925	421	7
1926	473	75
1927	515	111
1928	534	247
1929	421	562
1930	431	421
1931	431	336
1932	432	579
1933	497	504
1934	616	361
1935	646	352
1936	695	324
1937	712	400
1938	671	440
1939	635	408
1940	579	454
1941	629	568
1942	635	597
1943	617	774
1944	515	830
1945	549	799
1946	657	1,058
1947	832	942
1948	1,089	1,031
1949	1,114	1,030
1950	1,118	1,060
1951	1,247	1,074
1952	1,305	1,127
1953	1,543	1,174
1954	1,660	1,145
1955	1,605	1,358
1956	1,703	1,685
1957	1,658	1,745
1958	1,534	1,769
1959	1,602	1,840
1960	1,763	1,890
1961	1,881	1,910
1962	2,018	2,045
1963	2,009	2,126
1964	2,515	2,073
1965	2,604	1,862
1966	2,582	1,744
1967	2,834	1,760
1968	2,883	1,907
1969	2,795	1,801
1970	2,796	1,479
1971	3,103	1,070
1972	3,468	696
1973	3,849	359

Sources: 1873-1881: Mineral Statistics of the United Kingdom of Great Britain and Ireland. R Hunt. Mems. geol. Surv. Gt. Br.
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Gypsum

Virtually all the United Kingdom production of gypsum has been derived from deposits in England, those in Nottinghamshire accounting for the greater proportion of the country's output. About 35 per cent of the gypsum produced in 1973 came from Nottinghamshire, 25 per cent from Sussex and 22 per cent from the Vale of Eden. The remainder was produced at the Fauld mine in Staffordshire and the Sherburn No 2 mine in North Yorkshire. Since the Second World War there has been a considerable increase in output; production amounted to 3,849,000 tonnes in 1973 compared with 1,089,000 tonnes in 1948, representing an annual growth rate of 5.2 per cent.

Gypsum production in England probably began shortly after 1254, when gypsum plaster is said to have been first introduced to this country by Henry III who, following a visit to Paris, had plaster of Paris imported for decorative work. Gypsum for plaster manufacture was probably obtained initially as a by-product of the alabaster industry, which by this time had become well established at Tutbury and Chellaston. However, statutory records did not begin until 1873, after the principal gypsum deposits in Nottinghamshire had been brought into production around the mid-1800s; By about 1900 annual output from this county amounted to about 80,000 tonnes and reached 300,000 tonnes during the 1930s. In Sussex the Mountfield mine came into production in 1876, while in Cumbria gypsum was worked near Cotehill as early as 1828 and was quarried at Long Meg, near Lazonby, from 1879 until 1895, when underground mining commenced and continued until 1914. The Long Meg mine was re-opened in 1922. Gypsum was first quarried at Temple Sowerby around 1880, and at Kirkby Thore mining began in 1906, although workings existed there before 1860. Gypsum was formerly produced at the Barrowmouth mine near Saltom Bay, south of Whitehaven, but mining ceased there in 1908. In Northern Ireland, gypsum was produced at least as early as 1812 and a small output was last recorded in 1951.

Anhydrite

In the United Kingdom, anhydrite has been produced continuously since 1923, although output was not officially recorded until 1925; it is estimated that of the 50 million tonnes of anhydrite produced, the Billingham mine, opened in 1927, supplied over 32 million tonnes. Anhydrite used for ammonium sulphate manufacture at Billingham was obtained from the Cocklakes and Long Meg mines in Cumbria until 1926 and from the Hartlepool mine between 1925 and 1930, until the Billingham mine itself came into full production. Substantial increases in output took place after 1954 with the opening of the Sandwith mine near Whitehaven and the development of a large new mining area at Long Meg, total United Kingdom output reaching a maximum of 2,126,000 tonnes in 1963. Production of anhydrite has declined markedly due largely to the closure of the Billingham mine in 1971, while at the Long Meg and Newbiggin mines production of anhydrite for sulphuric acid manufacture ceased early in 1973.

The last officially recorded value of gypsum and anhydrite output was £3,623,000 in 1958, but the corresponding figure for 1973 has been estimated by the Institute of Geological Sciences to be £7.0 million. This figure represents the value of gypsum and anhydrite as mined or quarried. A further measure of their importance in the national economy is the very considerable value added to them as raw materials by subsequent industrial processing and manufacture. Virtually all the anhydrite produced at present is used captively in the manufacture of sulphuric acid. The gypsum industry is also vertically integrated and the finished products (plaster and plaster board) may have a value of between 6 and 20 times the ex-mine or quarry value of the gypsum used in their manufacture.

Overseas Trade

Imports, consisting essentially of raw gypsum and gypsum plasters, are relatively small, amounting to 211,07·1 tonnes in 1973 (Table 3), while exports of gypsum and gypsum plasters amount to about 14,000 tonnes a year.

There is no overseas trade in anhydrite. In 1973 the value of imports (c.i.f.) of gypsum and gypsum plasters, exceeded exports (f.o.b.) by £558,000 and trade in 'Articles of Plastering Material' (mainly plasterboard) added a further £1,305,000 making a total deficit on trade (including c.i.f. charges) of of £1,863,000.

Imports and exports of gypsum-based products have been described under the United Kingdom Tariff and Overseas Trade Classification since 1970 as: 'Gypsum; anhydrite; calcined gypsum and plasters with a basis of calcium sulphate whether or not calcined but not including plasters specially prepared for use in dentistry'. Code number 2520 0005 relates to 'Calcined gypsum and plasters with a basis of calcium sulphate (including plaster of Paris, Keene's cement)' and code number 2520 0083: 'Other' refers to raw gypsum.

Imports

Imported gypsum and gypsum plasters almost entirely from the Irish Republic and France (Table 3), supply coastal plasterboard plants at, for example, Glasgow and also cement works on the Thames Estuary, these plants enjoying the benefit of more favourable delivery costs by sea compared with those arising from road or rail transport. All the gypsum produced and exported from the Irish Republic is produced by a member of the BPB Industries Group.

Gypsum plaster and plasterboard exported from the Irish Republic to the United Kingdom is destined largely for Northern Ireland. Imports of manufactured items, including plasterboard, are detailed under code number 6810 0007: 'Articles of Plastering Material' and consist essentially of plasterboard exported from the Irish Republic to Northern Ireland.

Table 3 United Kingdom: Imports of gypsum and gypsum products, 1971-1973

	1971		*1972*		*1973*	
	Tonnes	*£ c.i.f.*	*Tonnes*	*£ c.i.f.*	*Tonnes*	*£ c.i.f.*
Gypsum (2520 0083)						
From: France	42,784	117,875	20,245	56,327	42,410	173,052
Irish Republic	71,813	157,669	98,169	190,466	107,799	268,652
Federal Germany	413	5,091	124	2,226	22	1,759
Other countries(a)	133	10,365	86	8,477	10,442	59,643
Total	115,143	291,000	118,624	257,496	160,673	503,106
Gypsum plasters (2520 0005)						
From: Irish Republic	19,037	205,241	23,414	270,314	44,528	414,131
Federal Germany	1,189	15,616	1,749	31,759	2,096	42,202
France	20	750	123	2,049	3,627	53,264
Other countries	374	15,718	170	19,105	147	17,110
Total	20,620	237,325	24,456	323,227	50,398	526,707
Articles of Plastering Material (6810 0007)						
From: Irish Republic	15,920	341,409	22,488	502,639	28,126	663,484
Other countries(b)	39	12,854	29	14,823	30,242	945,339
Total	15,959	354,263	22,517	517,462	58,368	1,608,823

(a) Including 5,344 tonnes valued at £28,962 from Morocco and 4,975 tonnes valued at £22,953 from Spain in 1973

(b) Including 29,258 tonnes valued at £897,394 from France in 1973

Source: HM Customs and Excise.

Exports

Relatively small quantities of gypsum plasters are exported annually (Table 4.) Exports amounted to nearly 8,000 tonnes in 1973, of which the Irish Republic was the principal country of destination. In addition, some 6,800 tonnes of gypsum was exported, notably to the USA, as well as over 2,600 tonnes of 'Articles of Plastering Material'. There are no exports of anhydrite.

Table 4 United Kingdom: Exports of gypsum and gypsum products, 1971-1973

	1971		*1972*		*1973*	
	Tonnes	*£ fob*	*Tonnes*	*£ fob*	*Tonnes*	*£ fob*
Gypsum (2520 0083)						
To: Irish Republic	972	27,600	879	24,785	823	25,933
USA	778	25,461	1,529	32,169	1,131	21,270
Yugoslavia	266	15,742	200	12,191	59	4,682
Other countries	2,256	83,083	1,234	34,660	4,741	85,763
Total	4,272	151,886	3,842	103,805	6,754	137,648
Gypsum plasters (2520 0005)						
To: Australia	345	13,990	410	20,770	532	26,716
Denmark	436	21,197	184	14,902	103	6,568
Hong Kong	540	13,965	732	14,804	357	8,149
Irish Republic	542	14,554	1,296	39,505	1,764	64,512
Malaysia	234	11,540	151	10,400	166	12,513
New Zealand	381	10,990	322	7,005	235	6,035
Republic of South Africa	955	24,332	760	21,956	982	28,846
Sweden	65	10,613	20	1,015	117	6,703
Singapore	227	10,513	169	7,775	246	10,114
USA	457	12,447	235	12,871	453	25,160
Other countries	3,901	138,054	3,046	127,020	3,003	138,256
Total	8,092	282,195	7,325	278,023	7,958	333,572
Articles of Plastering Material (6810 0007)						
To: Belgium	3,310	73,496	20	2,129	23	11,429
Canada	23	14,771	233	54,361	28	26,894
France	344	29,625	1,567	65,629	66	10,918
Irish Republic	2,205	53,214	589	40,798	342	32,668
Israel	284	13,771	669	17,142	70	3,019
Federal Germany	42	13,378	186	21,166	1,018	17,192
USA	40	30,863	53	40,224	83	66,624
Other countries	846	95,611	351	98,770	1,016	135,327
Total	7,094	324,729	3,668	340,219	2,646	304,071

Source: HM Customs and Excise.

Demand Trends

Apparent consumption of gypsum and anhydrite (domestic production plus imports minus exports) was 4.4 million tonnes in 1973, of which 359,000 tonnes was represented by anhydrite. Apparent consumption of gypsum has risen significantly over the last 5 years, corresponding to increases in demand for plaster, plasterboard and cement. (Table 5). The Annual Minerals Inquiry run by the Business Statistics Office recorded that, of the total quantity of gypsum produced in 1973, 2,683,000 tonnes was used for plaster processing, 1,061,000 tonnes for cement and 105,000 tonnes for other purposes. It is estimated that approximately equal amounts of gypsum were consumed in the manufacture of plasters and plasterboard.

Table 5 United Kingdom: Plaster, plasterboard and cement production, 1969-1973

	1969	*1970*	*1971*	*1972*	*1973*
			Thousand tonnes		
Plaster (*a*) (*b*)	942	868	942	1,019	1,125
Finished Cement (*c*)	17,460	17,171	17,697	18,048	19.986
			Million square metres		
Plasterboard (*a*)	83	82	95	103	113

(a) Great Britain
(b) Excluding that for plasterboard
(c) Excluding cement clinker

Source: United Kingdom Mineral Statistics 1974, Institute of Geological Sciences.

The spectacular increase in the demand for gypsum in the Twentieth Century and particularly since the last World War is attributable to the general expansion of the building industry, together with a more widespread use of plaster and particularly plasterboard as building materials. The rising demand for these products is expected to increase the demand for gypsum, bearing in mind that the building industry is particularly sensitive to economic conditions and government policy.

Consumption of anhydrite for sulphuric acid and other purposes (chiefly ammonium sulphate until 1971) for the period 1960-1973 is shown in Table 6. Its use in sulphuric acid manufacture is no longer economically attractive because of the ready availability of supplies of relatively cheap crude sulphur from overseas sources. Although it appears likely that sulphuric acid production at Whitehaven will be based exclusively on imported crude sulphur in the near future, production of anhydrite may not cease entirely as new markets for the mineral are being sought. During the early 1960's the United Kingdom was a major producer of ammonium sulphate, reaching a peak consumption of anhydrite for this purpose in 1963, when just over 1 million tonnes of ammonium sulphate was produced. Production of ammonium sulphate from anhydrite ceased at Billingham in 1971.

The sulphur crises in the early 1950s and mid-1960s encouraged the increased use of anhydrite for sulphuric acid manufacture, with the result that anhydrite accounted for as much as 21 per cent of the sulphuric acid made in 1968. However the use of anhydrite as a substitute for imported crude sulphur has fallen dramatically (Fig 9) with the cessation of sulphuric acid manufacture from anhydrite at Billingham in 1971 and at Widnes in 1973, as well as the replacement of some of the anhydrite kilns at Whitehaven by crude sulphur burners.

Table 6 United Kingdom: Consumption of anhydrite, 1960-1973

Thousand tonnes

	For sulphuric acid *(a)*	For other purposes *(b)*
1960	772	1,118
1961	716	1,194
1962	876	1,169
1963	857	1,269
1964	957	1,116
1965	992	870
1966	995	749
1967	1,154	606
1968	1,278	629
1969	1,229	572
1970	1,204	275
1971	1,051	20
1972	741	—
1973	388	—

Sources: *(a)* National Sulphuric Acid Association Limited.

(b) Total production of anhydrite less consumption for sulphuric acid.
United Kingdom Mineral Statistics 1974, Institute of Geological Sciences.

Substitutes

Large quantities of calcium sulphate are produced as waste in the preparation of phosphoric acid by the 'wet' process, in which phosphate rock is digested with sulphuric acid. Approximately 5.5 tonnes of this *phosphogypsum* are made available per tonne of P_2O_5 in the phosphoric acid produced. In the United Kingdom, 2,030,000 tonnes of phosphogypsum were produced in 1972. Disposal presents a considerable problem and, as at most European phosphoric acid plants, takes place in the sea or in tidal estuaries (Table 7).

Table 7 Production and disposal of phosphogypsum in the United Kingdom in 1972

Location	*Method of disposal*	*Quantity tonnes*
Whitehaven	slurry pipeline to the sea	500,000
Immingham	slurry pipeline into Humber	500,000
Billingham	dumped on land	400,000
Avonmouth	slurry pipeline to Severn	350,000
Severnside	slurry pipeline to Severn	80,000
Aberdeen	slurry pipeline to sea	80,000
Leith	slurry pipeline to sea	120,000
Total		2,030,000

Source: W Gutt and M A Smith. *Chemy Ind.,* 1973, No 13, p. 613.

The calcium sulphate waste may form as anhydrite, hemihydrate or gypsum, depending on the temperature of the reaction and the concentration of phosphoric acid produced. The reaction can be expressed empirically as follows:

$$Ca_5F(PO_4)_3 \quad + 5H_2SO_4 \quad + 10H_2O \rightarrow 3H_3PO_4 \quad + 5(CaSO_4.2H_2O) \quad + HF$$

Phosphate rock Phosphoric acid + Phosphogypsum

Compared with natural anhydrite and gypsum, phosphogypsum has the disadvantage of a higher water content (about 25 per cent), fine particle size and, frequently, inconsistent quality. It may contain between 0.4 and 1.5 per cent P_2O_5 and up to about 1.5 per cent fluorine, both of which are objectionable in the manufacture of plaster, plasterboard and cement. Traces of radioactive material may also be present. Most phosphoric acid is made by a process in which the digestion of phosphate rock takes place at low enough temperatures (70 to 85°C) and concentration (28 to 32 per cent P_2O_5 product acid) to promote the formation of calcium sulphate in the dihydrate form. There are phosphoric acid processes, however, which give rise to purer forms of phosphogypsum.

Phosphogypsum is not used commercially in the United Kingdom at present although it was used in the early 1930's by Imperial Chemical Industries Limited (Agricultural Division) at Billingham, initially to provide plaster for internal plastering of walls and ceilings and later mainly to produce 'Pioneer' plasterboard. The process consisted of washing waste gypsum to remove soluble P_2O_5, correcting for excess acidity, and then filtering the gypsum crystals to give a cake containing 16 to 18 per cent water. The cake was then dried and carefully dehydrated to produce a hemihydrate. However, difficulties were encountered with quality control brought about by the presence of fluoride impurities in the phosphogypsum, and the process finally proved uneconomic. The plant produced up to about 100,000 tonnes of plaster a year of which about 62,000 tonnes was converted to about 8.4 million m^2 of plasterboard, mostly 9.5 mm thick. A plant was also commissioned at Severnside in 1966 which had a capacity of about 104,000 tonnes of plaster a year, producing some 11.3 million m^2 of plasterboard and about 35,000 tonnes of plaster. Operations ceased during the latter half of 1969. Interest is again being shown in the commercial utilisation of phosphogypsum because of the large quantities that are available, the expense of dumping a waste product, and the growing awareness of the need to minimise marine pollution.

In the Federal Republic of Germany, phosphogypsum is used in plasterboard manufacture, as a bulkhead material in coal mines and as a retarder in cement manufacture. A relatively new process developed by Gebr. Giulini GmbH, Ludwigshaven, involves subjecting washed phosphogypsum to flotation to remove most of the organic and some inorganic impurities and, with the addition of various chemicals, steam-heating in an autoclave where recrystallisation from the dihydrate to the hemihydrate gypsum takes place at temperatures of 110-120°C. A plant capable of processing about 160 tonnes of phosphogypsum a day came into operation at Ludwigshaven in 1966. Production of panels amounted to some 280,000 m^2 in 1971, almost 20,000 tonnes. Another plant at Castrop-Rexel, north-east of Dusseldorf, started operations in 1972 with a capacity of 50,000 tonnes a year using technology developed by Gebr. Knauf Westdeutsche Gipswerke, Iphofen. In France there is a plant of similar size at Les Roches-de-Combrieux near Bordeaux. Additional plants using phosphogypsum for plaster and plasterboard are being constructed elsewhere in Europe.

Several countries have considered the use of phosphogypsum for the production of sulphuric acid and cement clinker, particularly when an integrated chemical complex is situated inland, thereby avoiding serious disposal problems which would otherwise arise. A notable example is the complex at Phalaborwa in northern Transvaal, South Africa, where the first plant to be based entirely on phosphogypsum came into operation in 1972. The plant has a capacity of about 108,000 tonnes of sulphuric acid a year, and employs a process developed by Osterreichische Stickstoffwerke (now Chemie Linz) in Austria. This company operates a plant at Linz using a mixture of phosphogypsum and natural anhydrite. Phosphogypsum is used in some countries in the manufacture of ammonium sulphate, one of the largest plants having been established in India in 1966 with an annual capacity of about 100,000 tonnes of ammonium sulphate.

In Japan, where deposits of natural gypsum are small and of relatively poor quality, the cost of importing natural gypsum for the manufacture of plaster and plasterboard has encouraged the development of a phosphoric acid process which provides phosphogypsum suitable for commercial use. Phosphogypsum has been used in the preparation of various plasters since 1934 and since the Second World War has almost entirely replaced natural gypsum in plaster and plasterboard manufacture. In 1971 production of natural gypsum amounted to 585,000 tonnes, while that of synthetic gypsum totalled 3.4 million tonnes, of which 2.6 million tonnes was obtained from phosphoric acid manufacture and 0.8 million tonnes from flue gas desulphurisation. An important factor accounting for the substantial increase in consumption of phosphogypsum in Japan since 1959 has been the development there of the hemihydrate – dihydrate phosphoric acid process which provides a waste gypsum that is stated to be much superior to that produced by the dihydrate process. Phosphogypsum is also used on a large scale in Japan as a cement retarder; smaller quantities of chemical or synthetic gypsum, such as that made available in rayon manufacture, the production of sodium chloride from sea water, and by the reaction of powdered limestone with waste sulphuric acid arising from the manufacture of acid-activated clay (montmorillonite), are of sufficient purity and whiteness to be suitable for use in the ceramic and glass industries and for the preparation of dental and surgical plasters.

Phosphogypsum was employed on a large scale to reduce the salinity of the soil in England, as well as in France and the Netherlands, after the extensive coastal flooding suffered in 1953, and its use as plaster, in dealing with oil pollution at sea was suggested by the Warren Spring Laboratory during the *Torrey Canyon* incident in 1967. When sea water is added, the finely divided plaster sets hard and sinks to the sea bed.

Calcium sulphate, in the form of anhydrite, arises as a by-product of the manufacture of hydrofluoric acid (HF), which is produced by treating fluorspar (calcium fluoride, CaF_2) with concentrated sulphuric acid in rotary kilns or retorts. Approximately 4 tonnes of $CaSO_4$ are made available per tonne of HF produced, giving rise to some 130,000 to 140,000 tonnes of anhydrite in the United Kingdom each year. Hydrofluoric acid plants are situated at Runcorn, Avonmouth, Rotherham and Birmingham. The anhydrite contains unreacted sulphuric acid, inorganic salts derived from contaminants in the fluorspar, as well as up to 2 to 3 per cent residual fluorides which consist mainly of unreacted fluorspar. In some cases free hydrofluoric acid and sodium silico-fluoride may also be present. About 5,000 tonnes of the waste anhydrite made available at Avonmouth annually is used in the manufacture of 'Synthanite' floor screeds.

Industry

Gypsum extraction in the United Kingdom is dominated by British Gypsum Limited, who operate 10 gypsum mines and 5 quarries (Table 8), probably accounting for about 95 per cent of total production. The only other significant producer is The Associated Portland Cement Manufacturers Limited, who quarry gypsum at Kilvington, between Nottingham and Grantham for use as a retarder in Portland cement. Anhydrite is produced by Albright and Wilson Limited (Marchon Division) at Sandwith in Cumbria, and was produced by British Gypsum Limited on a substantial scale at the Long Meg and Newbiggin mines in the Vale of Eden until March 1973, to supply a sulphuric acid plant at Widnes in Lancashire. Both the Long Meg and Newbiggin mines continue to produce small quantities of anhydrite. Minor amounts of gypsum are produced by H J Baldwin and Company Limited at Bunny, south of Nottingham, in the course of quarrying Keuper Marl for brickmaking, and the output is sold to British Gypsum Limited.

British Gypsum Limited is the largest subsidiary of BPB Industries Limited, the forerunner of which was The British Plasterboard Limited. In 1917, BPB established the first plasterboard plant in the United Kingdom at Wallasey in Cheshire, based on gypsum obtained from independent producers in the Midlands and Cumbria. After becoming a public concern in 1932, the company greatly expanded capacity by extending its interests into gypsum mining through takeovers and mergers, and by the late 1950s a greater part of the gypsum mining, plaster and plasterboard manufacturing capacity in the United Kingdom had come under its control. BPB Industries Limited became the main holding company in 1965, with British Gypsum Limited taking responsibility for the Group's gypsum mining activities and plaster and plasterboard manufacture in the United Kingdom. At that time Bellrock Gypsum Industries Limited and ICI accounted for 25 per cent of the plasterboard market, but Bellrock Gypsum Industries was acquired by BPB in 1967 and the production of plasterboard (from phosphogypsum) by ICI ceased in 1969, so that British Gypsum are now the sole producers. A report by the Monopolies Commission on the plasterboard manufacturing industry was published in 1974. The company operates 14 plaster mills with an output in 1973 of about 1 million tonnes of building plaster; plasterboard factories are located at Glasgow, Cocklakes, Kirkby Thore, Sherburn-in-Elmet, East Leake, Staunton, Erith, Rochester and Robertsbridge. BPB Industries Limited also has subsidiary and associated companies overseas producing gypsum and plaster products in Canada, France, the Republic of Ireland, South Africa, Belgium, Sweden and Denmark. The associates are the major suppliers of plasterboard in France and Scandinavia and the sole manufacturers in Belgium.

Albright and Wilson Limited, which became a private limited liability company in 1892, is the largest producer in the United Kingdom of industrial inorganic and organic phosphorus compounds. In 1955 the company acquired Marchon Products Limited and its subsidiary Solway Chemicals Limited which, in the same year, began producing sulphuric acid at Whitehaven from anhydrite obtained nearby.

Table 8 The location and ownership of gypsum and anhydrite mines and quarries in 1974

CUMBRIA	
British Gypsum Ltd	Long Meg mine, Lazonby (a) Newbiggin mine, Newbiggin (a) Newbiggin quarry, Newbiggin New Stamphill mine, Kirkby Thore Longriggs mine, Kirkby Thore
Albright and Wilson Ltd (Marchon Division)	Sandwith mine, near Whitehaven (b)
NORTH YORKSHIRE	
British Gypsum Ltd	Sherburn No 2 mine, Sherburn-in-Elmet
NOTTINGHAMSHIRE	
British Gypsum Ltd	Marblaegis mine, East Leake Glebe mine, Gotham Jericho quarry, Newark-on-Trent Hawton quarry, Newark-on-Trent Grange quarry, Newark-on-Trent Cropwell Bishop quarry, Nottingham
The Associated Portland Cement Manufacturers Ltd	Kilvington quarry, Nottingham
H J Baldwin and Co Ltd	Bunny, East Leake
STAFFORDSHIRE	
British Gypsum Ltd	Fauld mine, Tutbury
SUSSEX	
British Gypsum Ltd	Mountfield mine, Robertsbridge
British Gypsum Ltd	Brightling mine, Robertsbridge

(a) Including some anhydrite

(b) Anhydrite

Very small quantities of gypsum are produced at Chellaston in Derbyshire by the Chellaston Brick Company Limited in the course of quarrying Keuper Marl for brick manufacture. The gypsum is stockpiled at present but could be utilised if a market was available.

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