Mineral Resources
Consultative Committee

Mineral Dossier No 3

Fuller's Earth

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Titles in the series

No 1	Fluorspar
No 2	Barium Minerals
No 3	Fuller's Earth

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.

Acknowledgements

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Contents

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
grammes (g)	=	troy ounces x 31.1035
kilogrammes (kg)	=	pounds x 0.45359237
tonnes (1000 kg)	=	long tons x 1.01605

Summary

Fuller's earth produced in the United Kingdom consists essentially of the clay mineral montmorillonite in which the principal exchangeable cation present is calcium. The mineral is highly adsorptive and absorptive, and possesses pronounced cation-exchange properties, which enable calcium montmorillonite (fuller's earth) to be converted to sodium montmorillonite (bentonite) by a simple base-exchange process. Fuller's earth has been worked in England since Roman times but until the 19th century was used entirely by the woollen industry for 'fulling' or cleansing woollen cloth. Nowadays fuller's earth and its sodium analogue bentonite have numerous industrial applications the more important of which are in glyceride oil refining, as a bonding agent in foundry moulding sands, as a suspension agent for oil well drilling muds and agricultural sprays, and for various civil engineering applications, as well as numerous other uses amongst which pharmaceutical preparations, such as face packs, are perhaps more popularly known.

Commercially valuable fuller's earth is confined, as far as is known, to the Jurassic and Cretaceous Systems, the mineral being worked by opencast methods from the Lower Greensand at Redhill in Surrey and Woburn in Bedfordshire and by drift mining from the Jurassic Upper Fuller's Earth Clay near Bath in Somersetshire. Opencast workings are backfilled with overburden and the land is restored, as far as possible, to its former condition. Underground mining causes some subsidence but providing the surface is suitably treated agriculture is only temporarily affected. Known reserves of fuller's earth are limited: the Lower Greensand is the most favourable horizon in which new deposits may be found.

Fuller's earth is processed by two different methods to give three main products; the natural earth, the sodium-exchanged earth and the acid-activated earth. Natural earth is processed by drying and grinding; the addition of small amounts of soda ash to the ground product yielding, in turn, the sodium-exchanged earth. Acid-activated earth is produced by treating the raw clay with either sulphuric or hydrochloric acid to increase its active surface and hence its adsorptive properties.

United Kingdom production of fuller's earth was about 176,000 tonnes in 1970 of which about 40,000 tonnes was acid-activated. Exports of fuller's earth and bentonite products were about 46,000 tonnes in 1970 and in the same year imports of bentonite (consisting principally of high grade Wyoming bentonite) were about 49,000 tonnes. There are two producers of fuller's earth in the United Kingdom, Laporte Industries Limited and Berk Limited, a subsidiary of the Steetley Company Limited. In addition, a number of other companies import raw bentonite (chiefly Wyoming) in bulk for milling and bagging in this country.

Definition and mode of occurrence

The term 'fuller's earth' is an unfortunate one from the mineralogical viewpoint and its definition, based on properties and out-moded uses has resulted in a great deal of confusion, particularly between trade and geological usage. Historically any clay which had the ability to adsorb[1] oil, grease and colouring matter, which therefore could be used for cleansing or 'fulling' woollen cloth, was known as a fuller's earth. A number of different clays have this property to a greater or less extent and have, therefore, been known as fuller's earth. Such material has been worked in Britain since Roman times and such place names as Bletchingley and Bletchley are derived from their association with areas where these adsorptive clays or 'bleaching earths' were worked. This century, however, advances in clay mineralogy have shown that the more effective fuller's earths are rich in the clay mineral montmorillonite and it is on this mineral that the definition is now based.

The structure of montmorillonite is such that 'exchangeable cations' are loosely held on the surface of the mineral the two principal varieties of montmorillonite being recognised by the nature of these 'exchangeable cations'. Montmorillonite with calcium as the principal exchangeable cation is known as fuller's earth, and is much commoner than the sodium-based form known as bentonite which, in view of its greatly superior physical properties in many industrial applications, is the more highly prized material. Fortunately fuller's earth has a strongly developed 'cation-exchange capacity' and can usually be converted to a bentonite-type montmorillonite (when wetted by the substitution of Na for Ca) simply by the addition of sodium carbonate. Thus, although natural bentonites are not found in the United Kingdom, fuller's earth can be utilised as such after suitable treatment, quality varying with the inherent nature of the clay.

Unfortunately, considerable confusion exists in the use of descriptive terms for montmorillonite clays and also between British and American terminology. Calcium montmorillonite and sodium montmorillonite are easily recognised by their respective properties for low or high swelling when in contact with water. The former are termed fuller's earth in Britain and 'non-swelling' bentonites in America. The latter are called bentonites in Britain and 'swelling' bentonites in America. The terms calcium and sodium bentonite are also commonly used to distinguish the two varieties. Further confusion arises by the use in America of the term fuller's earth for the attapulgite clays, which, although mineralogically unrelated to the montmorillonites, exhibit many similar properties and were originally used as a substitute for imported English fuller's earth. In addition, many geologists would restrict the term bentonite to montmorillonites which have formed as an alteration product of volcanic ash (the origin of the well-documented Wyoming bentonite) but the genesis of many montmorillonite deposits still remains unresolved.

[1] Distinction is made between the terms 'adsorption' and 'absorption', the former denoting a surface phenomenon whereby the adsorbed material is held on the surface of the mineral. In absorption the material is distributed throughout the body. Fuller's earth exhibits both adsorption and absorption.

Unfortunately the confusion does not end here, for in the United Kingdom the term 'Fuller's Earth' is also used for a lithostratigraphic division of the Middle Jurassic, only a small part of which (and only in some areas) contains montmorillonite as the main constituent.

In this report the term fuller's earth is applied to clay deposits in which the main constituent (and virtually the only clay mineral) is montmorillonite and the principal exchangeable cation is calcium. The formula $M(Al, Fe, Mg)_4 (Al, Si)_8 O_{20} (OH)_4 nH_2O$, in which the relative amounts of Al, Fe and Mg are not fixed, represents the main composition of montmorillonite. M represents the exchangeable cations Ca, Mg, Na, K and H, and nH_2O the hygroscopic water content.

There is no British Standard definition for fuller's earth although there are the following British Standard definitions for montmorillonite and bentonite:

B S 3446: 1962. 'Glossary of Terms relating to the Manufacture of Refractory Materials'.

Montmorillonite:	One of the clay minerals; the principal constituent of bentonite.
Bentonite:	A highly plastic montmorillonite clay, essentially derived from volcanic ash.

Montmorillonite is widely distributed in rocks, clays and soils in small amounts but is concentrated only in a relatively small number of commercially exploitable deposits. In the United Kingdom these deposits are known only in the Jurassic and Cretaceous systems; indeed, unaltered montmorillonite does not commonly occur in rocks older than the Jurassic, the exchangeable cation potassium becoming fixed, thereby changing montmorillonite to a mixed-layered illite/montmorillonite clay mineral.

Deposits of fuller's earth are usually lenticular in form, of limited extent and variable quality and are thought to have been formed by either the alteration of volcanic ash or the direct chemical precipitation of montmorillonite in shallow marine basins. All the deposits of fuller's earth worked in the United Kingdom consist essentially of calcium montmorillonite, but may also contain minor amounts of other clay minerals, carbonate and sulphate minerals and organic matter. Small amounts of feldspar, zeolites, apatite, sphene and even sphalerite may be present and are thought to be of authigenic origin. Limonite is present in weathered yellow varieties. Quartz is surprisingly uncommon, except in intercalated sand layers. The deposits consist of a greenish or bluish clay, which on weathering and oxidation turns a yellowish colour. The clay, in its natural state, has a soft and earthy texture with a soapy or unctous feel. When dry it may become very hard and brittle but when placed in water slakes easily and disintegrates to a clay slurry without becoming a paste.

Resources

In the United Kingdom commercial deposits of fuller's earth are at present known only in the Jurassic Fuller's Earth and Cretaceous Lower Greensand (*see* Fig 1). The most important deposit occurs in the Lower Greensand east of Redhill, Surrey, where it is worked by Laporte Industries Limited. The fuller's earth beds extend approximately 9 km along the strike of the Sandgate Beds from between Reigate and Redhill to Godstone. The Sandgate Beds increase in thickness along the strike from Redhill to Nutfield, where they attain a maximum of 21 m (7 m in seven separate beds being fuller's earth) but thin to 6 m with no fuller's earth at Bletchingley although they expand again to 9 m (with 0.75 m of fuller's earth) south of Godstone. The various beds of fuller's earth differ considerably in extent, thickness and quality; only the thickest seam, averaging 2 to 3 m and attaining a maximum of 5.5 m, is worked between the eastern outskirts of Redhill eastward to the village of Nutfield, a distance of approximately 2.5 km. There is a northward dip of the beds of between 5 and 10^{o} so that the overburden of Folkestone Beds increases in this direction. The main bed is worked between thicknesses of 1.5 m and 5.5 m and beneath 1.5 to 30 m of overburden; it appears to thin out northwards.

Another important deposit of fuller's earth occurring within the Lower Greensand (Woburn Sands) is worked by Berk Limited near Woburn in Bedfordshire. In Aspley Wood a horizontal bed of fuller's earth, covering an area of approximately 2.5 square kilometres and varying in thickness between 2.5 m and 3.75 m, is worked beneath 24 m to 30 m of loosely consolidated ferruginous sand. The Lower Greensand rests unconformably on Oxford Clay and the fuller's earth bed appears to occupy a shallow basin in the underlying Jurassic strata. To the ENE of Woburn at Clophill, a further deposit of fuller's earth in the Lower Greensand was discovered by the Institute of Geological Sciences in 1934. The bed varies between 0.75 and 2.5 m in thickness with an overburden of about 6 to 7.5 m. The Fuller's Earth Union Limited (now Laporte Industries Limited) obtained planning permission for this deposit in 1952 and it was worked until 1964. It is understood that the deposit is being held in reserve.

Fuller's earth also occurs within the Lower Greensand around Maidstone in Kent and this area was the centre of the fuller's earth industry until about 200 years ago. The fuller's earth occurs mostly as a single bed, up to 2 m thick, at the top of the Sandgate Beds. The bed is almost continuous along the main outcrop eastwards of Maidstone to Bearsted, but only traces of fuller's earth can be seen beyond Leeds, 3 km south-east of Bearsted.

West of Maidstone fuller's earth occurs in outliers of the Sandgate Beds for a distance of about 6.5 km. Fuller's earth has been worked near Grove Green, at Sandling, north of Maidstone and north of Barming Heath. The fuller's earth bed dips north-eastward beneath the Folkestone Beds and appears to thicken in this direction as 3 m of fuller's earth was discovered at a depth of 70 m in a borehole at Thurnham. At present no fuller's earth is worked in the area although Laporte Industries' deposit at Grove Green is expected to be worked again in the near future. A clay described as a fuller's earth was worked in the past from a deposit to the north of Leeds. The material, however, did not consist of a montmorillonitic clay and according to the definition used in this dossier should not be termed fuller's earth.

In 1969 the Institute of Geological Sciences outlined two deposits of fuller's earth within the Lower Greensand in the vicinity of the villages of Fernham and Baulking, to the south of Faringdon, Berkshire. In each deposit two beds of fuller's earth were present, the upper and thicker bed being the most extensive occupying an area of 0.95 sq km at Baulking and 0.86 sq km at Fernham.

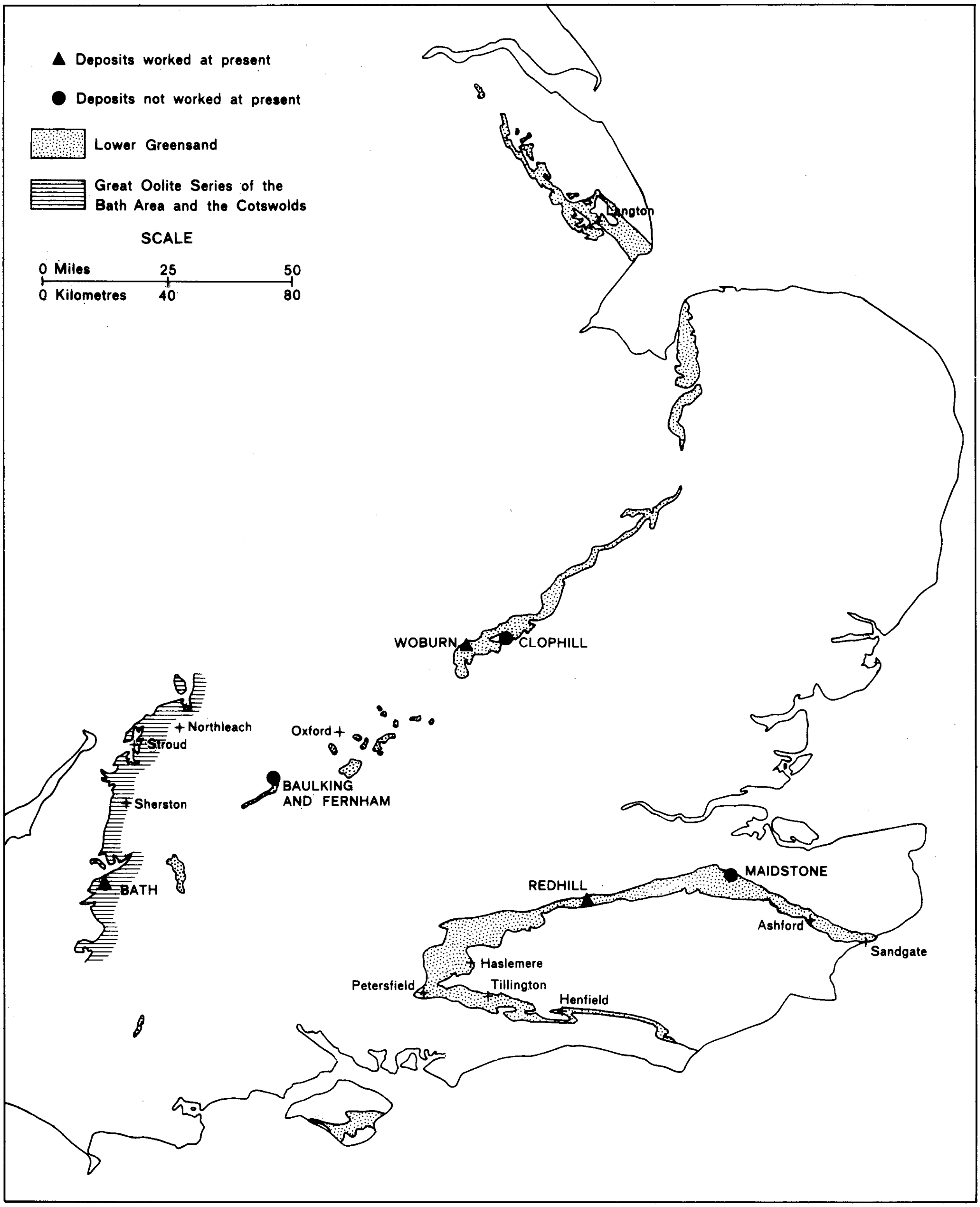

Fig 1. Location of the major known fuller's earth deposits in the United Kingdom

At Baulking, the upper bed has a mean thickness of 1.45 m, beneath a mean overburden of 11.9 m, and at Fernham a mean thickness of 1.07 m beneath a mean overburden of 14.6 m. The lower bed is less extensive and in each deposit has a mean thickness of 0.82 m. The quality of the fuller's earth beds is not uniform owing to the presence of intercalated detrital sand layers, but the quality of the separated montmorillonite is comparable to, if not better than, commercial fuller's earths at present produced in the United Kingdom. An estimated 4.45 million tonnes of fuller's earth are present in the two deposits.

Good commercial fuller's earth together with some inferior material occurs in the top 2 to 3 m of the Upper Fuller's Earth Clay in the Middle Jurassic near Bath, Somersetshire. The present fuller's earth workings exploit the material from underground levels driven into the hillside below the Great Oolite limestone plateau at Combe Hay, south of Bath. Jurassic fuller's earth differs somewhat from Cretaceous fuller's earth in that it contains appreciable amounts of calcite.

Numerous brief references to the occurrence and past working of fuller's earth may be found in the literature; a brief summary of some of this information is given below. It must be remembered, however, that the original definition of fuller's earth was based on commercial application and had no mineralogical significance and a number of these occurrences are probably not therefore montmorillonite clays.

In south and south-eastern England most of these other occurrences of fuller's earth are confined to the Lower Greensand of the Weald. In Kent thin seams of waxy clay, 23 to 60 cm thick, and known to consist mainly of montmorillonite, have been found at the top of the Sandgate Beds north of Saltwood and west of Sandgate and near the base of the Folkestone Beds at Willesborough Lees, near Ashford. To the north of Haslemere thin seams of waxy clay resembling fuller's earth are present in the Sandgate Beds and there are a number of references to the past working of fuller's earth near Headley in Hampshire. Small quantities have also been reported occurring in the Sandgate and Hythe Beds, south of Guildford and apparently the earth was once dug from the Hythe Beds near Tillington, west of Petworth. Beds of yellow and blue clay occur at the top of the Sandgate Beds around Petersfield and a seam 1.2 m thick of fuller's earth was recorded in a well in the Sandgate Beds at Henfield in Sussex. Within the Lower Greensand of central and eastern England fuller's earth has been recorded in beds averaging 1 to 1.5 m thick in the area south of Oxford, as thin seams 15 to 23 cm thick in the area around Brill, Buckinghamshire, and as thin seams not more than 2.5 cm thick at Ingoldsthorpe in Norfolk. A sample of fuller's earth from the Sutterby Marl at Langton in Lincolnshire was examined by the Institute of Geological Sciences but found to contain only minor amounts of montmorillonite.

The Jurassic Fuller's Earth extends from the Dorset coast through Somerset into the Cotswolds but fuller's earth deposits have only been worked near Bath at Combe Hay, English Combe, Odd Down, South Stroke, Midford, Lyncombe, Widcombe and Wellow. The montmorillonitic clays, however, also occur in the Gloucestershire Cotswolds district, where there have been small workings in the past. An impure bed of fuller's earth has been recorded at Notgrove, near Bourton-on-the-Water, Gloucestershire and montmorillonitic clays were discovered in the Fuller's Earth Clay at a depth of 37 to 41 m in the Stowell Park borehole, near Northleach, Gloucestershire. This clay contained 30 to 55 per cent calcite and quartz was also present.

Samples of the Lower Fuller's Earth Clay from a number of boreholes in the vicinity of Stroud, Gloucestershire have been examined by the Institute of Geological Sciences but only minor amounts of montmorillonite were found to be present, the material being contaminated by calcite and a second clay mineral, illite. A sample of Upper Fuller's Earth Clay from a borehole at Sherston, near Malmesbury, Wiltshire was, however, found to contain a major proportion of montmorillonite although the clay was again contaminated with calcite.

At Emborough in Somerset 'fuller's earth' has been worked on a small scale from the Tea Green Marl and Westbury Beds (Rhaetic) and at Binegar, 'fuller's earth' was also reported to have been worked from the Harptree Beds (Lower Lias – Inferior Oolite). The extent, quality and clay mineralogy of these deposits are not known. A small deposit, said to be of 'fuller's earth', has been worked at North Wick on the south-eastern flank of Dundry Hill, west of Bath. This deposit and a record in the shaft of Priston Colliery appear to be of Lower Lias age, but again the extent and quality is not known.

A deposit at Treamble, near Truro, Cornwall was worked as a 'fuller's earth' in the past, but the clay has been found to consist mainly of kaolinite. 'Walker's earth' (a local term for fuller's earth) occurring in the Silurian of Wales and the Welsh Borderlands has also been worked, but analyses of this material have shown it to consist mainly of an interstratified illite-montmorillonite clay mineral. 'Fuller's earth' has also been recorded near Bala and Corwen, North Wales, in the Isle of Man and at a number of localities in Scotland and in the Midlands, where at the end of the last century the material was reported to have been worked on a small scale from the Cambrian Stockingford Shales at Nuneaton.

The two producing companies continue to assess their reserves and undertake exploratory work on their own behalf. The Institute of Geological Sciences have discovered new deposits in Berkshire in the course of field mapping, but as the known reserves of workable fuller's earth are limited and production continues to increase a systematic investigation of United Kingdom resources is being planned by the Institute.

The most favourable horizon in which new deposits of fuller's earth may be found is undoubtedly the Lower Greensand. This formation outcrops over a substantial area in south-eastern England with isolated patches in Wiltshire, Berkshire, Oxfordshire and Buckinghamshire and a more continuous outcrop north of Woburn extending into Norfolk and Lincolnshire (*see* Fig 1). Further investigation of the Lower Greensand may lead to the discovery of new deposits, although these may be lenticular in form and of relatively small extent (perhaps less than one square kilometre) and may occur beneath significant thicknesses of overburden. The evaluation of clay deposits with their varying clay composition, chemical activity and physical properties can present considerable problems in establishing economic working levels. It is interesting to note that where the Lower Greensand is unconformable on Jurassic rocks, fuller's earth beds sometimes occur in infilled valleys and troughs in the Jurassic strata. An interpretation of the subsurface topography may therefore be a useful guide to the discovery of further deposits. The Jurassic Fuller's Earth extends from the Dorset Coast to the Cotswolds and although the stratigraphy of this formation has been studied in some detail, little is known of the distribution and character of the clay minerals within the sequence. However, from the limited information available it is known that montmorillonite clays are not confined to the area to the south and south-east of Bath but extend further north into Gloucestershire, although fuller's earth of commercial quality has yet to be discovered in this area. Montmorillonite is not an uncommon mineral in many rocks and clays of post-Jurassic age, and in some of the Tertiary clays of London and the Hampshire Basins (eg the London Clay), it may be the dominant clay mineral and locally achieve relatively high concentrations.

Land use

Fuller's earth is worked by both opencast and underground mining methods and the mode of occurrence of the strata is such that it is possible, within limits, to plan its extraction to precede development of the land for other uses. Only a limited amount of land is, therefore, temporarily sterilized by mineral workings.

The working technique adopted in opencast quarrying is to extract the mineral in strips, with soil and other overburden removal preceding the mineral extraction, the restoration of worked-out ground following close behind. Opencast working of fuller's earth is similar to that of most opencast coal and ironstone operations in that it involves a high ratio of overburden to the mineral seam extracted. Replacement of the overburden thus almost restores the former surface level. In the Nutfield area, however, the overlying Folkestone Sands is sold for use as building and industrial sand, a particular advantage as the thickness of the overburden increases. At Nutfield, worked-out areas have been restored and made into sports fields for a Surrey County Council Secondary School for the Deaf and for the local village, and a bird sanctuary is at present under construction. About 95 per cent of the worked-out areas are restored to agriculture. At the workings near Woburn Sands in Bedfordshire, the cut is backfilled with overburden as the mineral is extracted and reafforestation of the worked-out areas is undertaken.

As reserves of fuller's earth are limited the mineral operators claim that all potential reserves should be protected. Fuller's Earth Regional Conferences were constituted by the Minister of Housing and Local Government in 1951, with the following terms of reference:

i. To ensure that reserves are not unnecessarily sterilised by surface building or other land use.

ii. To ensure that suitable reserves of fuller's earth are made available to meet production requirements.

iii. To ensure that working of fuller's earth does not unnecessarily interfere with other uses of land and is not unnecessarily harmful to public amenity.

At the South West Regional Conference held in 1952, concern was expressed at the rate at which the nation's already inadequate reserves were being used. It was, therefore, considered imperative that all actual and potential reserves should be protected by the planning authorities as far as possible. Reserves which were known to lie within the pre-1951 Bath City boundary (ie north of Wansdyke) were written off owing to either actual or potential sterilization by surface buildings. It was recognised in the approved Somerset Development Plan that proven and potential deposits in Somerset should be protected from sterilization and in the current review the local planning authority proposes to allocate approximately 1.25 square kilometres for the working of fuller's earth. This includes areas for which planning consent has been given and areas of known reserves.

In Surrey, at the end of 1971, the areas permitted for the working of fuller's earth amounted to about 4 square kilometres. The original line of the proposed London to Crawley motorway (M23) cut across the Redhill deposits, and would have sterilized, it was estimated, over a million tonnes of fuller's earth. The Ministry of Transport (now the Department of the Environment) reconsidered their proposals and a new line was decided upon further east, which was more acceptable to Laporte Industries Limited. It was found difficult to avoid the deposits altogether without interfering with school building proposals and the village of Bletchingley. Consideration has been given to the practicability of allowing prior extraction of the fuller's earth from the proposed site of the road and a triangle of land to the south-east. It has been estimated that between 50,000 and 100,000 tonnes of fuller's earth would be sterilized if the land to the south-east of the proposed road line could not be worked.

At Combe Hay mine in Somerset, fuller's earth is extracted from underground workings 18 to 25 m below the surface. The main haulage adits are supported by semi-circular steel arches and where the adit passes beneath a road the roof is further strengthened with concrete. The working adits are supported by timbering and, in addition, a thin limestone bed just below the overlying Great Oolite is left to support the roof. To ensure support for the Bath-Radstock road (A367) a safety margin of 23 m from the edge of the road is left unworked. The nature of the underground working does, however, cause subsidence, usually within three months, the land generally falling in a regular plane but remaining suitable for agricultural purposes providing the surface of the affected area is suitably treated. After initial subsidence there is a risk of further subsidence usually for a period of five to seven years, owing to the collapse of underground supports in former workings. Reinstatement of the surface is undertaken by the mineral operator. Extraction of fuller's earth therefore has very little practical effect on agricultural production, either here or elsewhere. In order to enable the land to consolidate for the purpose of surface building it should be left for a further period of about twelve years after the secondary subsidence.

Processing plant and other surface buildings are associated with the opencast workings within which the draglines and other plant operate. The operations give rise to some noise and, in dry weather, dust. However, planning conditions are imposed to safeguard the local amenity interests as far as possible. The processing plants and other surface installations are comparatively unobtrusive, there being little or no smoke, smell, spoil or effluent. Waste aluminium and iron oxides from the Cockley acid-activation plant at Redhill are disposed of in worked-out areas.

Uses

Fuller's earth is valued for its sorptive (adsorptive and absorptive) properties, catalytic action, bonding power and pronounced cation-exchange capacity, which enable it to be easily converted to sodium montmorillonite, which in turn exhibits thixotropy. These properties are related to the structure of the clay mineral montmorillonite, which is presented diagrammatically in Fig 2 showing that montmorillonite is composed of sheets of silica-alumina-silica units stacked in the c direction. In the octahedral alumina sheet some aluminium ions have been replaced by lower-valency iron and magnesium ions leaving unsatisfied negative charges within the crystal structure. These charges are balanced by exchangeable cations, usually calcium or sodium, which lie between one sheet and the next.

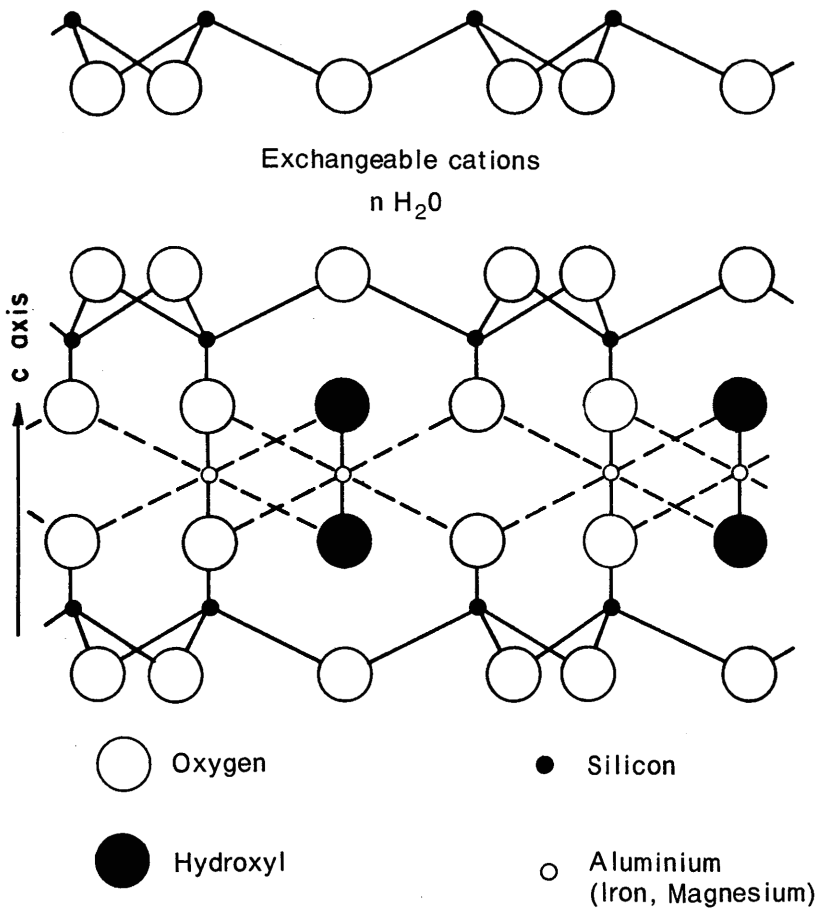

Fig 2. Diagrammatic illustration of the theoretical montmorillonite structure.

Such cations are mobile and give rise to the base-exchange properties of montmorillonite, which enables the mineral to adsorb cations selectively from solutions in polar liquids. The bleaching or decolorising property of fuller's earth is more complicated, and montmorillonite's ability to adsorb acid substances and non-electrolytes from non-polar liquids, such as glyceride oils, is probably due to hydrogen bonding. Acid-activation increases the adsorptive capacity of the clay by replacing the exchangeable cations with hydrogen and dissolving out Al, Fe and Mg, thereby increasing the surface area and porosity of the mineral. The catalytic properties of fuller's earth depend on the acidic surface characteristics and large surface area of montmorillonite. Between the silica-alumina-silica sheets, water and other polar molecules, such as certain organic molecules, can enter and are bound by Van der Waals' forces. The formation of several layers of water molecules, particularly when sodium is the main exchangeable cation present, causes the one dimensional reversible swelling of the lattice. In water the clay particles effectively cleave apart causing a separation of the lamellar units to produce a suspension of very finely divided and extremely thin plates possessing important rheological properties. The plate-like particles have negative charges on the surface and positive charges on the edges and in suspensions of quite low solid content the particles orientate themselves negative to positive and form a structure with a jelly-like appearance, called a gel. On agitation the weak electrical bonds are broken and the dispersion becomes a fluid with a high viscosity. This indefinitely reversible property is known as thixotropy and is widely used in civil engineering applications, oil-well drilling muds and numerous other suspension applications.

Montmorillonite, particularly the sodium form, exhibits good bonding properties and is used for bonding foundry moulding sands, pelletising iron ore concentrates and binding animal feedstuffs. Calcium montmorillonite usually develops a high green and sodium montmorillonite a high dry compressive strength, so that a wide range of requirements can be met by using different types of montmorillonite and varying the composition of the clay/water mix. In bonding moulding sands, for example, the large surface area of montmorillonite enables the sand grains to be coated with a thin film of clay, which, with the aid of water, bonds the sand to a rigid mass. However, a small increase in the water content makes the sand slightly plastic and therefore easier to mould into the required pattern.

The more important commercial applications of montmorillonite in relation to its physico-chemical properties are summarised in Table 1. The use of natural fuller's earth, the activated earth and the sodium-exchanged form (sodium montmorillonite) are discussed in greater detail below.

Table 1. Commercial Applications of Montmorillonite in Relation to its Physico-Chemical Properties

1.	*Cation exchange capacity*	Preparation of bentonite from fuller's earth Preparation of organophilic montmorillonites
2.	*Sorptive properties (May be increased by acid treatment)*	
	a) In suspension	Refining and bleaching of glyceride oils Clarification and purification of sugar solutions, syrups and wines Water purification, sewage and effluent treatment
	b) In dry state (or paste)	Pharmaceutical and therapeutic preparations Absorbent (oil spillage on factory floors, pet and animal litter)
3.	*Surface area (May be increased by acid-activation)*	Catalytic action, carrier for catalysts Carrier for insecticides and fungicides Mineral filler and extender
4.	*Rheological properties (Modification of flow properties of fluid medium)*	
	a) Viscosity and suspending powers	Drilling muds Paints (both oil and water based) Fertilizer sprays Bitumen emulsions Formulations for ceramic glazes
	b) Thixotropy	Wall support for boreholes Civil engineering (diaphragm wall construction) Non-drip paints
5.	*Impermeability, coating properties*	Civil engineering (grouting) Drilling in permeable strata
6.	*Bonding properties*	Bonding foundry moulding sands Pelletising iron ore concentrates Pelletising animal foodstuffs
7.	*Plasticity*	Formulation of mortars, putties, adhesives, some ceramic bodies

(*After* J A Bain, Geochemical Division. Institute of Geological Sciences)

Natural fuller's earth

Since classical times fuller's earth has been used for scouring and degreasing wool, a process known as 'fulling', but only a very small proportion of present-day output is used for this purpose. One of the main uses of the natural earth is in the refining of liquids, especially oils, although in many applications it has been superseded by the activated earth. In glyceride oil refining the natural earth is used for bleaching very sensitive oils, such as coconut oil, or for the final clarification of very light oils. Natural fuller's earth is used in oil refineries for soap scavenging and for refining mineral oils, when only a mild bleach is required. The natural earth is also used in sugar refining and as a catalyst in some organic reactions, although here again it is being increasingly replaced by activated fuller's earth. The large surface area of the clay also makes it a suitable support for other catalysts. One of the best known uses of the natural earth, although it accounts for only small tonnages, is in pharmaceutical preparations, where it is used in some creams and foot powders, baby powders, face packs and therapeutic muds. Other important applications are as a carrier for insecticides and herbicides, as a floor absorbent for oils and for the disposal of the excreta of household pets, a relatively new use which is expanding rapidly. Natural fuller's earth is also used as a filler or dusting powder in some industries.

Acid-activated fuller's earth

Glyceride oils, that is edible oils and fats from vegetable and animal sources, are used in vast quantities and the majority must be bleached or decolorised by activated earth before use. The colouring matter and impurities in the oils are adsorbed onto the clay surface and it is here that the high surface area of the clay is all-important. Mineral oils, such as lubricating oils, are refined by activated earth and may be re-refined after use by similar treatment. The activated earth is also used to catalyse various Friedel-Crafts reactions, particularly during the alkylation of phenols, and also to promote polymerisation, isomerisation, cyclisation and dehydration. In addition activated earth is used as a delicate pH adjuster, where the last traces of alkalinity have to be removed from organic liquids.

Sodium montmorillonite (Bentonite)

The sodium-exchanged form of fuller's earth exhibits most of the properties of its natural counterpart (bentonite), although usually to a lesser degree, and may substitute for practically all its uses. Both calcium and sodium montmorillonite are used extensively in the foundry industry for bonding synthetic foundry moulding sands in iron and non-ferrous work, but natural sodium montmorillonite (eg Wyoming bentonite) is the much preferred material for steel foundry work because of its durability (that is, its bonding properties are not destroyed by moderate heating) and higher fusion temperature. Wyoming bentonite is, however, also used in many iron foundries in preference to the sodium-exchanged clay, particularly when high quality castings are required and high pressure moulding machines are employed. Bentonite is usually added to new silica sands in proportions of 4 to 6 per cent, although

8 to 10 per cent is used for high pressure moulding. Moulding sands may be re-used with a further addition of 0.1 to 1.0 per cent clay. Sodium-exchanged montmorillonite is also used as a binding agent in the preparation of animal and poultry feed cubes and pellets and bentonite is used extensively in the USA, Canada and many other countries for pelletising iron ore concentrates to improve handling prior to smelting, a use which is expanding rapidly.

Sodium montmorillonite slurries, exhibiting pronounced thixotropic properties, are finding increasing use in civil engineering. For example, slurries containing 4 to 8 per cent of sodium montmorillonite are used for grouting (that is making strata such as sand and gravel impermeable, for example, in the foundations for tunnels and dams) for diaphragm wall construction (providing non-mechanical support for walls of trenches, during piling, and in other excavations) and as a lubricant in sinking caissons, bored piles and similar foundations. When sodium montmorillonite grouts are used alone, the gelling property can be broken down by vibration or a high hydrostatic head. When irreversible gels are required the sodium montmorillonite is used in combination with cement or certain silicates. Sodium montmorillonite is also an effective additive to mortar to improve its pumpability. Experiments are at present being conducted which may lead to the development of a bentonite soft ground tunnelling shield which, it is hoped, will make possible the mechanisation of tunnelling through soft strata such as sand and gravel. A bentonite slurry is pumped into the tunnel face, which it stabilises by gelling, enabling the cutters to excavate the gravel and bentonite gel. The bentonite is then separated and recirculated for further use.

Sodium montmorillonite is used as a suspension agent in fresh water muds in rotary drilling (in the presence of salt-saturated water, sodium montmorillonite flocculates and settles). The suspension carries the drill cuttings to the surface and by gel formation prevents these, and weighting agents such as barytes, from settling out when drilling is not in progress. The suspension also provides an impervious coating for the walls in permeable strata, gives support to the sides of the drill hole, lubricates the bit and rods and helps to support the weight of the drilling equipment with increasing depth. Other suspension applications of sodium montmorillonite are int he production of agricultural sprays, fungicides and insecticides, water and emulsion paints, ceramic glazes and bituminous emulsions; sodium montmorillonite may also be used as a flocculant for purifying domestic water supplies. Organophilic derivatives of montmorillonite are used in paints, greases, printing colours, waxes, adhesives, mastics and emulsions to increase their viscosity and therefore improve their suspension and spreading properties. They are also used as the bond in waterless moulding mixes for the production of non-ferrous castings and as an additive to some lubricating greases to stabilize their consistency with change in temperature.

'Laponite' is the trade name for a synthetic sodium lithium magnesium silicate clay having a similar composition and swelling properties to the naturally occurring clay mineral hectorite, a rare lithium magnesium-rich montmorillonite possessing superior thixotropic properties to Wyoming bentonite. It is used in water-based systems as an inorganic gelling, suspending, plasticising and emulsifying agent in, for example, emulsion paints and printing inks, ceramic glazes and vitreous enamels, cosmetic and pharmaceutical preparations, aerosols and adhesives.

Specifications

There is no recognised minimum montmorillonite content for an acceptable commercial grade of fuller's earth, as this depends as much on the projected use of the clay itself as on its montmorillonite content. For example, the montmorillonite content of Redhill and Woburn fuller's earth is relatively high and uniform (generally in excess of 80 per cent) and the clay is suitable for most uses, but at Bath the presence of substantial amounts of calcite makes the clay unsuitable for the production of acid-activated earth. The calcite content varies over the thickness of the bed, being some 30 to 40 per cent at the top and between 10 and 20 per cent in the lower and middle sections. The high calcite material is quite suitable for use as a carrier for fertilizers and insecticides and as a cattle food binder but is generally not acceptable for use as a foundry bonding clay. A wide range of grades of fuller's earth are marketed and specifications for the various grades are available from the two producing companies.

Specifications for bentonite as an ingredient of drilling muds are published by the Oil Companies Materials Association in Specification No DFCP - 4. Drilling Fluid Materials. Bentonite. (London: 1969). 7 pp.

Tentative acceptance specifications for bentonite as a foundry moulding material are given in Specification No 3, 1967 of the British Steel Castings Research Association (now Steel Castings Research and Trade Association). A specification for bentonite for pharmaceutical purposes is published in the British Pharmacopoeia. (London: The Pharmaceutical Press, 1968), pp 92-93.

Price

Prices are normally subject to negotiation but appear to vary between £15 and £40 per tonne, delivered, depending upon grade. Activated fuller's earth is the higher priced material.

Nominal prices for fuller's earth and bentonite are published regularly in the journal *Industrial Minerals.* Quotations in January 1972 were:

> Fuller's earth, natural, foundry grade, 1 - ton lots, del UK, £15 to £16.50 per long ton [£14.76 to £16.24 per tonne].
>
> Bentonite, Wyoming, foundry grade, 85 per cent through 200 mesh, bagged 5-ton lots, del, £24 to £26 per long ton [£23.62 to £25.59 per tonne].

Technology

Fuller's earth is won by both opencast and underground mining methods. At Redhill and Woburn the overburden, which has a maximum thickness of about 30 m and consists mainly of sands, is removed by tractor-scrapers and dragline excavators, the last few inches of overburden often being removed by hand to minimize contamination. At Redhill hard calcareous sandstone beds occurring above the fuller's earth bed are broken up by ripper-dozers and drop ball. The fuller's earth is removed by Caterpillar or Michigan rubber-tyred shovels and dragline excavators and loaded into lorries for transport to the works. Following extraction of the mineral, worked-out areas are restored for agricultural use or reafforested. At Combe Hay, south of Bath, a 2 - 3 m seam of fuller's earth is worked by underground methods from adits driven into the Upper Fuller's Earth Clay below the Great Oolite Limestone at a depth of some 18 - 25 m. The clay is extracted by hand with compressed air picks and is transported from the face in rail cars drawn by electric locomotive. Selective mining is undertaken to separate the highly calcitic upper part of the bed from the remainder, the two grades having different end uses. According to Laporte Industries Limited the cost of underground mining here compares favourably with opencast operations and an extraction rate of about 75 per cent is achieved. An experimental drift mine was developed at Redhill in 1962-3, but the ground was unstable and the project was abandoned.

The processing employed in the production of natural fuller's earth consists of drying and grinding. The raw clay is dried in oil-fired rotary louvre driers to remove surplus hygroscopic moisture and the dried earth is either marketed in the granular form or ground to a fine powder, size grading being carried out by air classification. The addition of small amounts of soda ash (usually 2 to 6 per cent) prior to drying and grinding converts the fuller's earth (calcium montmorillonite), when wetted again, into bentonite (sodium montmorillonite) by base-exchange. A number of different grades of bentonite products are prepared by varying the soda ash content; the finished products are stored in silos prior to bagging or delivery in bulk by road transport.

Organic montmorillonites are produced by reacting natural sodium montmorillonite or hectorite with long chain organic molecules, for example alkyl ammonium ions. The positive ammonium ions attach themselves to the negatively charged silicate layer and surround the montmorillonite crystal with organic alkyls. The clay becomes hydrophobic and exhibits thixotropic properties in organic liquids.

When fuller's earth is treated by acids, either to remove impurities, or to change its physical nature (largely by increasing the surface area available for reaction) its decolorising or bleaching power is greatly increased and it is then known as 'activated fuller's earth'. (Outside the United Kingdom the term 'activated' is often used to describe the sodium-exchange process for converting calcium to sodium montmorillonite.) At Laporte Industries Limited's Cockley works at Redhill two types of activated fuller's earth are produced by treating the natural earth with either hydrochloric or sulphuric acid. The sulphuric acid treatment is carried out at elevated pressures in tile-lined autoclaves using direct steam injection. Acid salts are removed by filtration washing and the clay filter cake is dried on a large spray drier or in oil-fired mills. The hydrochloric acid activation process employs a unique method of acid salt removal following the digestion stage, which produces a washed slurry at one end and a concentrated chloride filtrate at the other. The filtrate is further concentrated so that the hydrochloric acid may be recovered and re-used in the clay digestion stage. This prevents the discharge of an effluent containing soluble chlorides. The only waste product emerging from the circuit is a granular mixture of aluminium and iron oxides.

Production

United Kingdom fuller's earth production statistics, official and unofficial, are available from 1854. In the 117 years, 1854 to 1970, United Kingdom production has totalled about 4.1 million tonnes.

Table 2. United Kingdom: Production of Fuller's Earth by decades, 1854–1970

Period	*Thousand tonnes*
(1854 – 1860)	85
1861 – 1870	81
1871 – 1880	*na*
1881 – 1890	154
1891 – 1900	178
1901 – 1910	242
1911 – 1920	303
1921 – 1930	239
1931 – 1940	203
1941 – 1950	446
1951 – 1960	790
1961 – 1970	1,347
Total:	
1854 – 1970	4,068

na – not available

Sources:

1854–1947: Ministry of Fuel and Power; Report of the Mineral Development (Westwood) Committee, Cmd. 7732 (1949).

1948–1970: Institute of Geological Sciences; unpublished data supplied by the producing companies.

Since the Westwood Report in 1949 no official statistics of fuller's earth production have been released. For the purpose of this present report, however, the assistance of the two companies, Laporte Industries Limited and Berk Limited in making available production figures (which include natural, sodium-exchanged and activated fuller's earth), is gratefully acknowledged. This information has enabled the annual statistics shown in Table 3 to be constructed.

Table 3. United Kingdom: Production of Fuller's Earth, 1948–1970

Year	*Tonnes*	*Year*	*Tonnes*
1948	55,000	1960	102,000
1949	58,000	1961	104,000
1950	62,000	1962	105,000
1951	64,000	1963	109,000
1952	60,000	1964	119,000
1953	63,000	1965	136,000
1954	76,000	1966	140,000
1955	79,000	1967	135,000
1956	79,000	1968	153,000
1957	81,000	1969	170,000
1958	89,000	1970	176,000
1959	97,000		

Total United Kingdom production of acid-activated earth included in the 1970 production figure is believed to be about 40,000 tonnes.

Overseas trade and consumption

The United Kingdom is largely self-sufficient in fuller's earth and there is a sizeable export trade. However, domestically produced sodium-exchanged montmorillonite cannot compete with higher quality bentonites, principally the naturally occurring Wyoming bentonite, and consequently substantial tonnages are imported for specialised end uses, particularly in the foundry industry.

Exports

United Kingdom exports under the description: Bentonite (statistical code number 2507 0202) have been recorded by HM Customs only since the beginning of 1970. These are believed to consist largely of sodium-exchanged montmorillonite and a smaller proportion of re-exported Wyoming bentonite after milling and bagging in the United Kingdom. Details of exports for 1970 and 1971 are shown in Table 4.

Exports of natural fuller's earth (calcium montmorillonite) and activated fuller's earth are not separately recorded by HM Customs. However, a measure of the total United Kingdom exports of fuller's earth and bentonite products is provided by the following figures which have been compiled from information supplied by the producing companies:

		Tonnes			
1965	1966	1967	1968	1969	1970
34,000	37,000	34,000	41,000	45,000	46,000

No precise figures are available for the value of exports but it seems likely that in 1970 the value was in excess of £1 million.

Table 4. United Kingdom: Exports of Bentonite, 1970–1971

		Tonnes
To	*1970*	*1971**
Sweden	4,182	6,790
Denmark	3,409	2,428
Norway	1,081	4,116
W Germany	923	2
Spain	749	882
Ghana	701	51
Netherlands	634	725
Finland	575	293
Muscat & Oman	553	–
Irish Republic	365	49
Qatar	287	304
Kenya	230	28
Malaysia	203	204
Other countries	683	1,311
Total	14,575	17,183
fob value	£302,177	£287,506

Source: HM Customs and Excise. * Provisional figures

Imports

United Kingdom imports have been separately recorded by HM Customs since 1967 under the description; Bentonite (statistical code number 276 04 until 1969 and 2507 0202 since 1970), the details being as follows:

Table 5. United Kingdom: Imports of Bentonite, 1967 – 1971

			Tonnes		
From	*1967*	*1968*	*1969*	*1970*	*1971**
USA	22,198	27,613	39,758	42,099	41,959
Italy	2,701	2,662	4,187	2,543	2,556
Spain	2,489	914	1	–	–
Greece	1,764	776	–	860	850
Morocco	1,137	7	130	–	356
Netherlands	912	353	185	189	–
France	342	325	220	40	–
Port E Africa	183	181	406	1,400	867
Senegal	150	61	–	150	–
W Germany	80	836	46	25	16
Algeria	10	2	1,384	1,483	417
Eire	5	101	–	–	15
Malagasy	–	–	508	–	–
Cyprus	–	–	556	–	–
South Africa	–	–	–	203	–
Other countries	–	1	1	21	1
Total	31,971	33,832	47,382	49,013	47,037
cif value	£587,241	£788,693	£922,602	£812,274	£818,810

Source: HM Customs and Excise   * Provisional figures

Imports from the USA, which accounted for 86 per cent of the total in 1970, consist largely of Wyoming bentonite (natural sodium montmorillonite) with a smaller proportion of Californian hectorite. A substantial proportion of the remaining imports are believed to consist of sodium-exchanged montmorillonite.

Consumption

There are no published statistics relating to the consumption of fuller's earth and bentonite in the United Kingdom. An approximate figure of apparent consumption can, however, be produced by adding imports of bentonite to domestic production and deducting exports. Apparent United Kingdom consumption of fuller's earth and bentonite for the period 1967-1970 is as follows:

	Tonnes		
1967	*1968*	*1969*	*1970*
133,000	146,000	172,000	179,000

No consumption statistics by end use are available but the largest market for domestic and imported bentonite and fuller's earth is the foundry industry with an estimated consumption of approximately 75,000 tonnes per annum.

Demand trends

Prior to the end of the 19th century fuller's earth was mainly used by the woollen manufacturers for 'fulling' or cleansing cloth and woollen goods and during the early 18th century the mineral was considered so valuable to the British woollen industry that its export was prohibited. Since then however, fuller's earth has been replaced by soaps and chemical detergents so that to-day the use of fuller's earth in the textile industry has virtually ceased. During the 19th century two major new uses for fuller's earth were developed, in refining mineral oil (for the petroleum industry) and glyceride oil, and during the latter half of the 19th century England enjoyed an extensive export trade with America and Europe. At the end of the 19th century, however, attapulgite (fuller's earth in America) was discovered in Florida and England gradually lost the American market. Until the outbreak of the First World War Germany alone was importing English fuller's earth; when supplies were cut off Germany developed, by chemical treatment of an indigenous clay, an 'activated' earth with superior purification properties to both the American and English fuller's earths. Following the war both England and America became major importers of German activated clay but since 1930, acid-activated earth has been produced in England at Redhill and used largely in vegetable, animal and mineral oil refining and more recently as a catalyst. In recent years, however, a new process called hydrofining has almost completely replaced acid-activated fuller's earth in mineral oil refining.

During the Second World War when imports of Wyoming bentonite used as a binding agent for synthetic moulding sands were restricted, it was discovered that indigenous fuller's earth could be converted, by a simple base-exchange process, to sodium montmorillonite with similar properties to the naturally occurring material. This sodium-exchanged montmorillonite could substitute for most of the uses of Wyoming bentonite, particularly in iron foundry moulding sands, although its lower fusion temperature and durability precluded its use in steel casting moulding sands.

Since this discovery the foundry industry has been the major consumer of sodium-exchanged and natural fuller's earth and with the rise in production of iron and steel castings and the increasing use of synthetically bonded moulding sands demand has increased considerably. In addition, a wide range of new uses, based on the properties of sodium montmorillonite in suspension, were also developed for indigenous fuller's earth which resulted in a greatly increased demand, production having more than quadrupled since the end of the Second World War. New uses will undoubtedly be found for this versatile raw material and the present rate of growth is likely to continue.

Substitutes

Attapulgite or palygorskite, a highly absorbent non-swelling clay, marketed as fuller's earth in the USA, but not produced in the United Kingdom, has some of the industrial applications of English fuller's earth. The mineral is a hydrated aluminium-magnesium silicate and possesses a fibrous lath-like morphology. Attapulgite may be used as a purifying and decolorising agent in glyceride and mineral oil refining; as a floor absorbent for oils and greases; as a conditioning or anti-caking agent for industrial chemicals and fertilizers; as a carrier for insecticides, herbicides and other agricultural chemicals; as a suspending agent for liquid fertilizers and in oil well drilling muds, where the mud becomes saturated with salt water, as montmorillonite clays fail to maintain their viscosity in the presence of electrolytes. Attapulgite is also used as a viscosity builder, thickening agent, emulsion stabiliser and as a binder and filler. In the United Kingdom, however, attapulgite is mainly used as a floor absorbent and as a pet litter. Attapulgite (and sepiolite) is superior to montmorillonite for these purposes as the clay granules do not readily break down to fine particles when wet.

The price of American attapulgite marketed in the United Kingdom is in the region of £30 to £50 per tonne depending upon grade.

Sepiolite, a hydrous magnesium silicate, is a lath-shaped clay mineral closely allied to attapulgite. Sepiolite has been found to be as efficient as acid-activated montmorillonite in the bleaching of transformer oils although not vegetable oils. In the contact process of oil refining the needle-like structure of the clay mineral acts as a filter aid as well as having a bleaching effect. Like attapulgite, sepiolite can be used in oil well drilling muds where it is even more resistant to flocculation than attapulgite, although it has the disadvantage of not forming an impermeable lining to the borehole, as does bentonite. Sepiolite may also substitute for fuller's earth as a carrier for insecticides and catalysts, as a clarifying agent for glucose, as an additive to foundry moulding sands and as an absorbent of oils and greases. In the United Kingdom, however, imported sepiolite is mainly used as a floor absorbent, for pet litter, for refining certain grades of mineral oils, eg transformer oils, and for stone cleaning. The price of Spanish sepiolite marketed in the United Kingdom is substantially greater than fuller's earth, being in the region of £30 to £50 per tonne for most grades, although up to £90 per tonne for specialised grades.

Other types of clay may serve satisfactorily in place of fuller's earth for some uses, such as binding animal feed stuffs. An example of this, is 'Tensilac', a mixture of kaolinite, illite and finely divided quartz, produced at Tenterden, in Kent. Silicates, resins and oils have recently replaced montmorillonite to some extent as binders in foundry moulding sands.

Industry

There are only two producers of fuller's earth in the United Kingdom, Laporte Industries Limited and Berk Limited, a subsidiary of Steetley Company Limited since mid-1970. Laporte Industries' Organics and Pigments Division, which acquired the interests of the Fullers' Earth Union (formed in 1890 by the amalgamation of several operations at Redhill and Bath) in 1954, is the major producing company operating quarries and two processing plants at Redhill, Surrey, and a mine and plant near Bath, Somerset; the company is also the sole United Kingdom producer of acid-activated earth. Berk Limited, operate a quarry and plant near Woburn in Bedfordshire.

In recent years, the high cost of importing processed bentonite has led to the greater part of the United Kingdom's natural bentonite requirements being imported in bulk, the mineral undergoing final drying, milling and bagging in this country. Berk Limited, one of the largest suppliers, with processing facilities at Middlesbrough, import raw Wyoming and Italian bentonite and Californian hectorite. Wyoming bentonite is also processed by Balbardie Limited at their Wallasey plant and Irwell Minerals and Chemicals Limited at their plant at Eccles, near Manchester. Colin Stewart Minerals Limited process imported Wyoming and Greek bentonite at their Winsford plant in Cheshire.

Organophilic montmorillonites are produced in the United Kingdom under the trade name 'Bentone' by Abbey Chemicals Limited, a subsidiary of Berk Limited and the National Lead Company, New York. The synthetic clay 'Laponite' is produced by Laporte Industries Limited.

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