Mineral Resources
Consultative Committee

Mineral Dossier No 24

Fireclay

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London
Her Majesty's Stationery Office

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Acknowledgements

The help of the many organisations within the fireclay, ceramics and opencast coal industries in providing information and advice, and giving access to their operations, is gratefully acknowledged. Within the Institute of Geological Sciences the compiler would like to thank Mrs W. Khosla for work on the illustrations, Mr D. Bate for bibliographic services and other colleagues, both in the Minerals Strategy and Economics Research Unit and the Land Survey Divisions, for their constructive advice.

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 × 25.4
metres (m)	= feet × 0.3048
kilometres (km)	= miles × 1.609344
hectares (ha)	= acres × 0.404686
grammes (g)	= troy ounces × 31.1035
kilogrammes (kg)	= pounds × 0.45359237
tonnes (1000 kg)	= long tons × 1.01605
cubic metres (m^3)	= cubic feet × 0.028317

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Preface

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

Widespread and increasing interest in the mineral resources of the United Kingdom led the Committee to undertake the collation of 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. A series of dossiers is being produced, each of which is being circulated in draft to the relevant sectors of the minerals industry. They bring together in convenient form, in respect of each of the minerals, data which had previously been scattered and not always readily available. These dossiers are published for general information.

Summary

The term 'fireclay' is used in a generic sense and is largely restricted to seatclays. Fireclays are non-marine, sedimentary clays consisting essentially of kaolinite, mica and quartz in varying proportions, together with other constituents considered to be impurities, such as ironstone nodules and carbonaceous matter. They therefore exhibit a wide range of physico-chemical properties and no single clay is suitable for every application. Fireclays were originally used for refractory purposes, but they have also important non-refractory applications, mainly in the manufacture of vitrified clay pipes and buff facing bricks, and to a lesser extent in stoneware pottery, sanitaryware and tiles. There is a declining demand for fireclay in its traditional application in the refractory industry, although the use of fireclay in the manufacture of buff facing bricks has increased in recent years.

Fireclays, being mainly confined to coal-bearing strata where they commonly, but not always, underlie coal seams, are mainly of Carboniferous age. A major and increasing proportion of total output is therefore derived from opencast coal mines. There are, however, important exceptions, for example, the high quality, refractory fireclays within the Passage Group of central Scotland are not associated with economically important coals. Refractory fireclays are also produced by underground mining.

In 1980, United Kingdom production of fireclay was 1.2 million tonnes, its lowest level since records of production began in 1873. There has been a significant decline in the number of mines, mainly underground, since the Second World War, reflecting the increasing production of cheaper fireclays from NCB and licensed opencast coal mines. Present production exceeds demand and large stockpiles have been built up in some areas, particularly in the Midlands. The future of the opencast coal industry has a considerable bearing on the long term availablity of fireclay, but with the recent and proposed increases in opencast coal production concern has been expressed at the loss of fireclay because of the wide imbalance in demand for the two minerals.

Definition and mode of occurrence

Originally the term 'fireclay' was applied to certain Carboniferous clays which exhibited refractory properties and which could be used for lining furnaces and making crucibles. The clays were found in coal-bearing strata, often, although not always, directly underlying coal seams, the close association of coal, fireclays and ironstones being a factor of considerable economic significance during the 18th and 19th centuries. These fireclays are unbedded mudstones, which are also characterised by the presence of carbonised rootlets (*Stigmaria*), the lack of evident sedimentary bedding being due to the reworking action of roots. Until comparatively recently the term 'fireclay' was widely used by geologists to refer to these rootlet beds irrespective of their refractory properties. In British geological usage the term has now been replaced by 'seatearth' (or 'seatrock'). However, seatearths exhibit a very wide variation in composition ranging from almost pure clayrocks through silty and sandy sediments to quartz-rich sandstones, which were themselves formerly valued as refractory raw materials (ganisters). Essentially clayey (argillaceous) seatearth is referred to as 'seatclay', and is known as 'underclay' in North America. The term 'fireclay' is now restricted to those seatclays which, because of their inherent physico-chemical properties, have commercial value for both refractory and non-refractory applications and this terminology is used throughout this report. Thus, whilst most fireclays are seatclays, by no means all seatclays can be regarded as commercial sources of fireclay.

Seatearths are rootlet beds (palaeosols) and represent periods when water was sufficiently shallow to allow colonisation by land plants. Over vast, low-lying flood plains extensive, non-marine swamp forests developed which typically gave rise to peat, and ultimately, coal formation. Although seatclays are thus mainly developed below coal seams and may also occur as partings within a seam, they are not always overlain by coal. They typically exhibit a sharp upper contact, a factor of some commercial significance in opencast coal mining, since it allows very thin (0.1 m) coal seams to be extracted. The sharp contrast between stratified coal above and unbedded seatearth below is usually particularly marked, although a thin carbonaceous mudstone or shale may separate the two. The lower boundaries to seatclays are commonly gradational.

Controversy still exists over the origin and the precise relationship between seatclays and their associated coal seams. Seatclays vary widely in thickness, usually ranging from less than 0.5 m to 2 m, although locally rootlets may extend over 6 m or more. There is, however, no relationship between coal and seatclay thicknesses and, since large amounts of peat would be required to produce some coal seams, not all the vegetation preserved in the overlying coal seam can have been rooted in the seatclay. Seatclays may have developed their mineralogical character before the onset of peat formation. Originally the *in situ* leaching action of plants growing in a water-logged, acid swamp environment was believed to be the major agency for the removal of fluxing constituents such as alkalis and alkaline earths. More recently, however,it has been suggested that at least some seatclays derived their inherent mineralogy outside the basin of deposition, in a source area undergoing tropical weathering and that *in* *situ* modification was of only minor importance. The climatic conditions prevailing in the source area and the intensity of weathering may have been an important factor controlling the mineralogy of seatclays. Many seatclays also show a vertical variation in their content of quartz which often becomes increasingly abundant towards the base, with a corresponding increase in clay content towards the top. Upward fining suggests that sedimentation and detrital sorting also played a part, particularly in concentrating highly kaolinitic seatclays. Some *in situ* leaching action may have taken place as evidenced by the presence of clay ironstone (siderite, $FeCO_3$) nodules where these are found concentrated towards the base of a seatclay. However, ironstone nodules may be found irregularly distributed in seatclays and typically they tend to be much more irregular in shape than those occurring in bedded mudstones. Nonetheless some seatclays show signs of having been raised above the water table, aerated and well-drained, causing the removal of iron and, at least in some cases, the oxidation of sulphur (in pyrite) and carbon.

Seatclays vary in colour from brownish to light grey to black; in general, darker colours indicate a higher carbon content. Some show a red or lilac mottling. Many clay-rich seatclays have a smooth, waxy texture and often exhibit randomly orientated listric surfaces. Some seatclays are hard but develop plasticity on weathering or fine-grinding, although others are very hard and have a very low plasticity.

Seatclays consist of kaolinite, hydrous mica (illite) and quartz in varying amounts, these three components often making up over 90 per cent of the rock. Other common, although minor, constituents include chlorite and other clay phases, carbonaceous matter (as coaly material and fossil debris), siderite, mainly present as clay ironstone nodules of varied size, and sometimes pyrite. Spherical grains of sphaerosiderite less than 1 mm in diameter are sometimes present and both these and ironstone nodules may represent a serious impurity in commercial fireclays. Other minerals, such as anatase (TiO_2) occur in very minor amounts. The kaolinite in seatclays is of the b-axis disordered variety (formerly referred to as fireclay mineral or 'livesite'), but apparently showing a range of disorder, the crystallinity index decreasing with decreasing particle size. The relative proportions of kaolinite, mica and quartz in some commercial fireclays is shown diagramatically in Fig. 1.

It seems likely that with seatearths in general an almost continuous series exists between kaolinite-rich (aluminous fireclays) and quartz-rich (ganisters) end members, with varying proportions of mica. Many fireclays exhibit both lateral and vertical variation in quality, both in the relative proportions of the component minerals present and in the amount and type of impurities, which may lead to problems in producing a consistent product. Nonetheless, in most coalfields there are fireclays which apparently retain their basic characteristics on a regional scale.

Kaolinite is the most important constituent of fireclays, being either dominant, as in refractory fireclays, or present in roughly equal proportions with other major components, as in non-refractory fireclays. In this respect fireclays have similar bulk mineralogies to ball clays and, since mineralogy greatly influences the ceramic properties of clays, similarities in their respective properties are likely. However, ball clays, being geologically younger and less indurated, are much more plastic than fireclays and are whiter-firing because of their lower impurity, mainly iron, content. Nonetheless, some fireclays have fired colours comparable

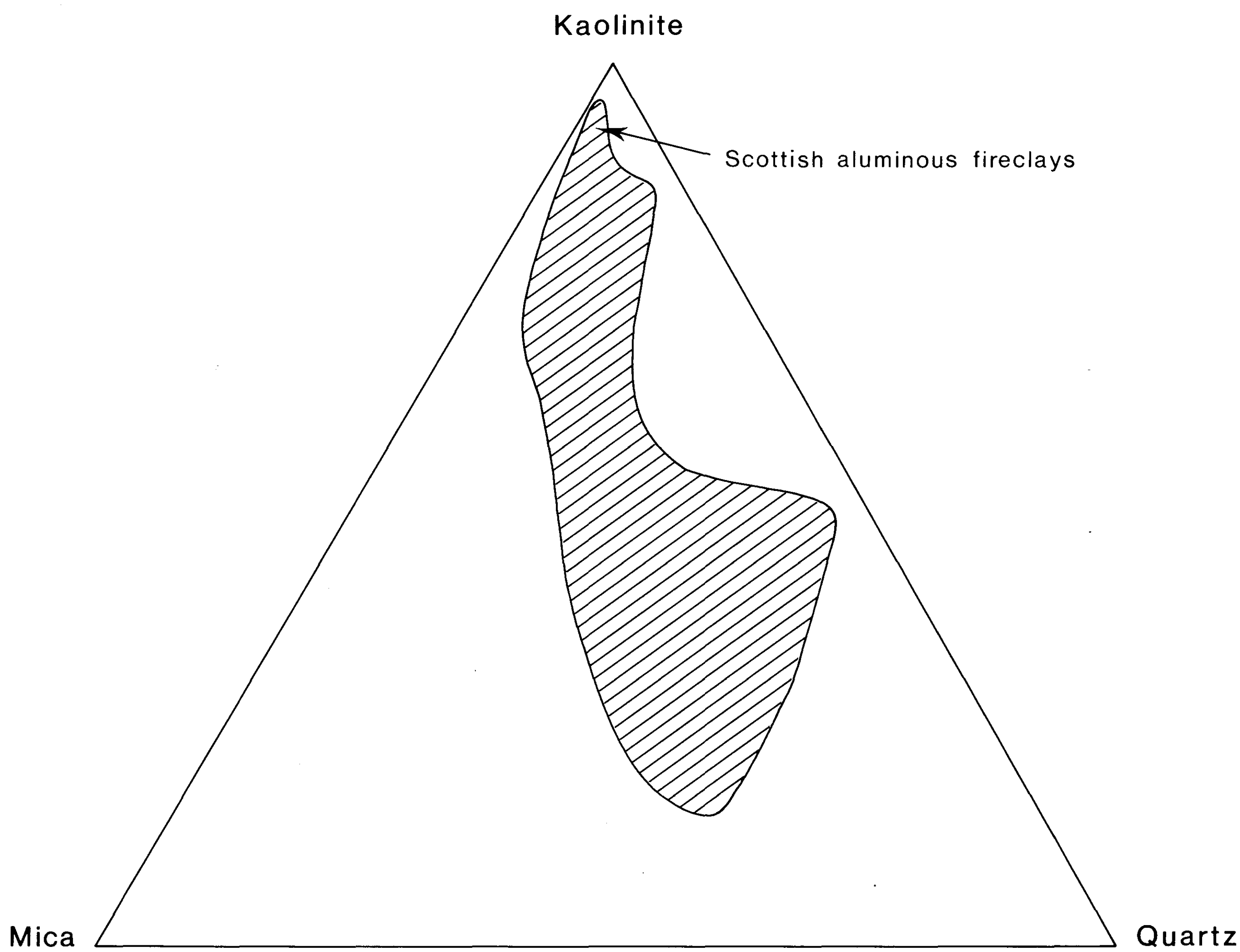

Fig 1 Diagrammatic illustration of the relative amounts of kaolinite, mica and quartz in some commercial fireclays.

to those of low-grade ball clays. With increasing quartz and mica relative to kaolinite, fireclays may have compositions comparable to those of Coal Measures mudstones and are used, in some instances, for the same application, for example in the manufacture of vitrified clay pipes.

Properties and uses

The industrial applications of fireclays are at present confined almost entirely to the ceramics industry, so that their suitability rests primarily on their behaviour during firing and use. The ceramic properties of fireclays are essentially controlled by their mineralogy, that is, the relative amounts of kaolinite, hydrous mica (illite) and quartz, their grain size and crystal perfection, and the amount and type of impurities present. A number of general relationships exist between the mineralogy and the ceramic properties of fireclays. For example, those with dominant kaolinite are refractory, whilst those with higher proportions of mica and quartz have important non-refractory applications.

Refractoriness is the ability of a material to withstand high temperatures without deforming or becoming chemically unstable. Since fireclays consist of several components, they soften and melt over a wide range of temperature when heated; the range between initial liquid formation and the start of deformation is known as the vitrification range. The more refractory a fireclay, the higher the temperature before vitrification, that is before initial liquid formation begins, and, usually, the longer the vitrification range.

The refractoriness of fireclays depends largely on the Al_2O_3:SiO_2 ratio and the phase diagram for this binary system broadly illustrates the behaviour of fireclay and other aluminosilicate refractories (*see* Fig 2).

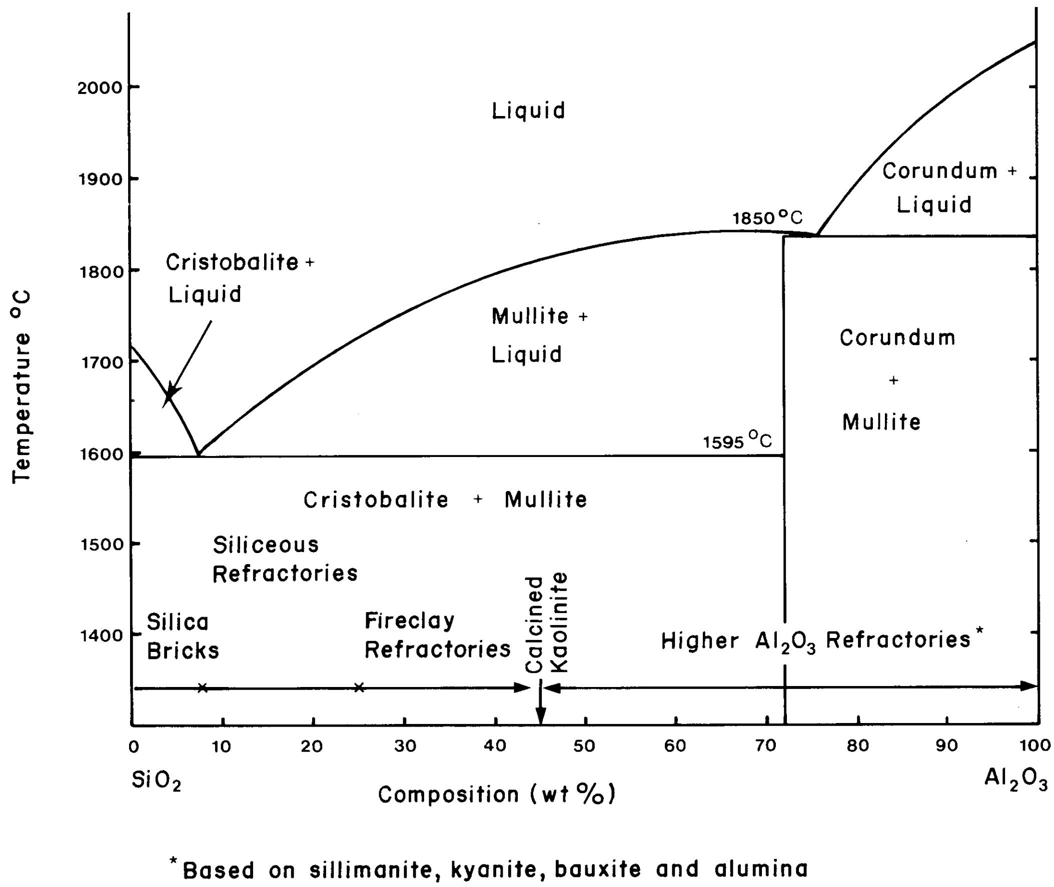

Fig 2 Phase diagram for the binary system Al_2O_3: SiO_2. (Based on Aramaki and Roy. *J. Am. Ceram. Soc.*, 1959, Vol. 42, No. 12, pp. 644-645).

The eutectic at 1595°C, i.e. the lowest temperature at which complete melting occurs, corresponds to a composition of 92.5 weight per cent SiO_2 and 7.5 weight per cent Al_2O_3. With increasing alumina (and silica), refractoriness is increased. For compositions containing 7.5 to 72 per cent Al_2O_3 at temperatures between 1595°C and 1850°C, the melting point of pure mullite ($3Al_2O_3.2SiO_2$), needle-shaped crystals of mullite occur in a viscous liquid. More of the liquid phase is present as the alumina content falls or temperature increases (leading to deformation). The more mullite present in a refractory body, the better its refractory properties. In theory, therefore, the alumina content of a fireclay is a good guide to refractoriness, which is measured by pyrometric cone equivalents (PCE), that is the temperature at which standard pyrometric cones (for example Seger Cones) bend under standardised conditions. In practice, however, the amount and type of fluxes present, such as alkalis (K_2O,Na_2O), alkaline earths (CaO, MgO) and ferrous oxide (FeO), have a marked effect on the refractoriness of fireclays, significantly reducing the temperature of initial liquid formation. For example, liquid formation in the ternary system K_2O-Al_2O_3-SiO_2 begins at 985°C. Fluxes therefore prohibit the imposition of a simple classification on the basis of alumina content alone.

Kaolinite ($Al_2O_3.2SiO_2.2H_2O$), which contains a maximum of approximately 45 per cent Al_2O_3 on a calcined basis, is the main source of alumina in fireclays. Since kaolinite converts to mullite and a liquid phase (forming a glass on cooling), increasing kaolinite means an increasing mullite content in the fired brick which gives better working strength, density (mullite is denser than glass), spalling, creep and chemical resistance. Hydrous mica, as the principal source of fluxes (mainly the alkalis K_2O and Na_2O), reduces refractoriness and shortens the vitrification range. As vitrification proceeds through progressive fusion of the clay the proportion of glassy bond increases, filling pores and reducing porosity, thus increasing the density, fired strength and impermeability of the body, but lowering thermal shock resistance and creep resistance (refractoriness under load). Increasing kaolinite content at a given temperature, has the effect of increasing porosity and thus reducing fired strength. High density, low porosity bricks are generally more resistant to attack by slags, molten metal and abrasion. During manufacture, therefore, fireclay refractory bricks are generally fired to achieve maximum density and dimensional stability in service. Fine-grained minerals tend to react more quickly than coarser particles so that a fireclay containing fine-grained mica will be tend to densify (vitrify) more readily than one containing coarser particles. Plasticity usually increases with increasing fineness of grain size, which also improves green and dry strengths but results in higher drying and firing shrinkage. Non-plastic components such as quartz or grog (crushed firebrick) have the reverse effect. However, quartz on firing undergoes expansion in converting to its various polymorphs and can lead to disruption in the fired article.

The main impurities in fireclays are iron, carbon and sulphur and their variable distribution is one of the major problems encountered in fireclay mining. Iron affects the fired colour of a clay and may significantly reduce its refractoriness. Iron occurs mainly as siderite (ferrous carbonate) nodules of varied size down to minute grains of sphaerosiderite less than 1 mm in diameter, which are particularly serious since they are difficult to identify during mining. Ferric oxide does not significantly reduce refractoriness if maintained in an oxidising atmosphere, but ferrous oxide acts as a powerful flux. About 3 per cent total iron oxides is generally regarded as the maximum permissible in the unfired fireclay, but much depends on the particular application, and up to 4 or 4.5 per cent may be acceptable for vitrified clay pipes where fired colour and refractoriness are not of any consequence. Carbon, present as organic matter, is a common impurity in fireclays because of the reducing conditions under which they were deposited. The presence of carbon is serious and carbonaceous matter must be fully oxidised before the onset of vitrification, which usually begins at approximately 900°C. At about this temperature pore closure and shrinkage occur, preventing ingress of oxygen and the escape of the gaseous oxides of carbon, thus producing local reducing conditions and leading to the phenomenon known as 'black coring' or 'black hearting'. Ferrous carbonate is converted to ferrous oxide which produces black glassy silicates, seriously reducing the refractoriness of the brick and leading to problems where uniformity of colour is important. In addition, since pores are effectively sealed, gases are prevented from escaping, leading to bloating and distortion in extreme cases.

$$Fe_2O_3 + C \longrightarrow 2FeO + CO$$

Carbon levels must generally be less than 2, and preferably less than 1 per cent, the precise amount that can be tolerated depending on the ease with which carbon can be oxidised. This will depend on such factors as the grain size and density of the body and the firing cycle adopted. Oxidation, or 'carbon burn-out' typically occurs at temperatures ranging between 350° and 850°C. Somewhat higher carbon levels can be tolerated if the body is held between 600°C and 900°C during firing to allow oxidation to take place. The extent to which this is practicable with modern fast cycle tunnel kilns is limited, however, although the problem is less acute with continuous chamber kilns. Alternatively, high carbon fireclays can be precalcined to burn out the carbon before incorporation in the ceramic body. In both cases costs are significantly increased. However, there have been recent developments in the introduction of oxygen into the kiln atmosphere, which results in faster carbon burn-out, improved quality, increased production and savings on fuel consumption. The use of oxygen also allows some relaxation in acceptable carbon levels. Developments are also taking place in the use of low temperature calcination to remove combined water, carbon and sulphides prior to shaping. Sufficient plasticity is retained for forming, allowing the production of higher density and higher strength bodies which can then be fired to more precise dimensional tolerances. Energy savings may also result because faster-firing schedules can be used. These developments may have a signifcant effect on future raw material requirements, allowing the use of higher carbon clays than can at present be tolerated. Unlike the carbonaceous matter in ball clays, the carbon in fireclays does not contribute to plasticity. Sulphur, present in pyrite, also acts as a powerful reducing agent and should normally be less than 0.2 per cent SO_3. A low carbonate content is also desirable, since this tends to produce a non-oxidising environment in the pore structure.

Normal commercial practice, particularly in recent years, has been to blend several fireclays to achieve uniformity and the desired balance of properties. For example, a more refractory clay can be blended with a non-refractory (vitreous) clay to extend the latter's vitrification range, and excessive firing shrinkage can be overcome by adding a less plastic fireclay or a non-plastic material such as a grog, allowing bricks of high dimensional accuracy to be made from an otherwise unsuitable material. A range of fired colours can also be produced by blending. This synthesis of clay feeds to suit particular applications allows a much wider range of fireclays to be used, ensuring more efficient utilisation of resources. It has also tended to increase the amount of fireclay bought on the open market.

Fireclay is used in the refractory, vitrified clay pipe, facing brick, and pottery (subdivided into sanitary fireclay, stoneware pottery and pottery clay, and floor and wall tiles) sectors of the ceramics industry.

Refractories

Fireclay has historically been valued mainly as a refractory raw material, the iron and steel industry being by far the largest market, traditionally accounting for some 70 per cent of total home consumption of fireclay refractories. Despite a decline in demand due to changing technology and more demanding operating conditions, fireclay is still the main refractory by weight used in the industry. Fireclay refractories are also widely used by other industries which operate processes above a few hundred degrees. These include the cooler sections of rotary cement kilns, tunnel kilns, lime kilns, incinerators, kiln furniture, the walls, arches and flues of power station boilers, for certain applications in the glass industry (glasshouse pots and certain glass tank blocks), in non-ferrous metallurgy, anode baking furnaces and the safety linings for pots in the aluminium industry, domestic refractories and in reactors and stills in the chemical industry.

Fireclay refractories have alumina contents in the range 25 to 44 per cent and have pyrometric cone equivalents (PCE's) signifying softening points between 1,580°C and 1,770°C (Seger Cones 26-35). However, liquid formation or softening occurs over a wide range of temperature and since fired strength depends on a mullite/glass bond they are unsuitable for load-bearing applications at high temperature. High temperature strength is, however, improved with increasing alumina content. Normal service temperatures for fireclay refractories are several hundred degrees below their PCE's and for a 42 per cent Al_2O_3 Scottish firebrick the maximum would be about 1,500°C. Fireclay refractories are, however, used where they are exposed to temperatures approaching their PCE's for only a short time, as in the casting pit where they are in contact with molten steel ($>$1,600°C), although here refractory life is limited.

Fireclay refractories are often specified by alumina content (British Standard 1,758: 1966) although it is widely accepted, at least by the producers, that refractory performance and suitability for a particular application is dependent on many other factors. The accuracy of size and shape of firebricks, dimensional stability in service or even expansion (bloating), may be critical for certain applications. A high bulk density and low porosity generally improve resistance to metal and slag penetration, abrasion resistance and refractory life, so that lower alumina, less refractory fireclays, which more readily vitrify, are used for some applications. A high alumina fireclay is therefore not necessarily the best for every refractory application.

Fireclay refractories have a wide variety of applications in the iron and steel industry, but they are used outside the main reaction vessels, that is outside the blastfurnace and the steel converter. By far the largest quantities are used in the casting pit, where they are used in the brick lining in steel teeming ladles and as special shaped refractories used for the casting of steel (casting pit refractories). Most casting pit refractories are used only once, whilst ladle bricks last on average about 14 casts. Molten steel ($<$ 1,600°C) is tapped from the steel converter and run into teeming ladles which, until the introduction of the basic oxygen steelmaking process (BOS), were almost entirely lined with fireclay bricks. The much higher steel production rates achieved with the BOS process has necessitated more intensive use of teeming ladles which, unless a larger number of ladles are employed, can be achieved only by either a longer ladle life or quicker lining renewal. Consequently, alternatives to fireclay ladle bricks have been introduced although fireclay bricks still offer many

Table 1 Typical chemical analyses of selected fireclay refractory bricks

<table>
<tr><th></th><th colspan="6">Wt %</th></tr>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td>SiO_2</td><td>52.1</td><td>52.5</td><td>53.8</td><td>52.0</td><td>53.5</td><td>53.6</td></tr>
<tr><td>Al_2O_3</td><td>42.3</td><td>41.5</td><td>40.7</td><td>40/42</td><td>40.5</td><td>40.95</td></tr>
<tr><td>Fe_2O_3</td><td>2.7</td><td>2.9</td><td>2.4</td><td>3.5</td><td>2.5</td><td>2.27</td></tr>
<tr><td>CaO</td><td rowspan="2">1.0</td><td>0.3</td><td rowspan="2">0.9</td><td>0.4</td><td>0.3</td><td>0.23</td></tr>
<tr><td>MgO</td><td>0.4</td><td>0.5</td><td>0.1</td><td>0.14</td></tr>
<tr><td>Na_2O</td><td rowspan="2">0.6</td><td rowspan="2">0.7</td><td rowspan="2">0.7</td><td>0.2</td><td rowspan="2">1.5</td><td>0.27</td></tr>
<tr><td>K_2O</td><td>0.4</td><td>0.76</td></tr>
<tr><td>TiO_2</td><td>1.3</td><td>1.5</td><td>1.5</td><td>1.5</td><td>1.1</td><td>1.41</td></tr>
<tr><td>Refractoriness (°C)</td><td>1,770</td><td>1,750</td><td>1,763</td><td>1730-1750</td><td>+1,730</td><td>1,750</td></tr>
<tr><th></th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th></th></tr>
<tr><td>SiO_2</td><td>57.93</td><td>54.9</td><td>63.0</td><td>57.6</td><td>n.a.</td><td></td></tr>
<tr><td>Al_2O_3</td><td>32.8</td><td>37.40</td><td>29.0</td><td>34.4</td><td>23.28</td><td></td></tr>
<tr><td>Fe_2O_3</td><td>4.27</td><td>3.43</td><td>3.8</td><td>3.0</td><td>< 3.0</td><td></td></tr>
<tr><td>CaO</td><td>0.26</td><td>n.a.</td><td>0.5</td><td>—</td><td>< 0.2</td><td></td></tr>
<tr><td>MgO</td><td>0.81</td><td>n.a.</td><td>0.7</td><td>2.5</td><td>< 1.0</td><td></td></tr>
<tr><td>Na_2O</td><td>0.1</td><td rowspan="2">1.23</td><td>0.1</td><td rowspan="2">0.9</td><td>< 0.3</td><td></td></tr>
<tr><td>K_2O</td><td>1.98</td><td>1.6</td><td>< 3.0</td><td></td></tr>
<tr><td>TiO_2</td><td>1.42</td><td>1.35</td><td>1.3</td><td>1.5</td><td>< 1.5</td><td></td></tr>
<tr><td>Refractoriness (°C)</td><td>1,720</td><td>1,730</td><td>1,670</td><td>1,690</td><td>1,600-1,650</td><td></td></tr>
</table>

Source:

1 Scottish firebrick. 'Nettle D'. GR-Stein Refractories Ltd
2 Scottish firebrick. 'Docken'. Dyson Refractories Ltd
3 Scottish firebrick. 'Atlas + A'. United Fireclay Products Ltd
4 Scottish firebrick. 'Eagle'. Craigend Refractories Ltd
5 'Micklam 40'. British Steel Corporation
6 Scottish firebrick. 'Superaxe'. The Burn Fireclay Co Ltd
7 'Durham 31/33'. The North Bitchburn Fireclay Co Ltd
8 '36/38 Dry Press'. Samuel Wilkinson and Sons Ltd
9 Ladle Brick 'DLP'. Dyson Refractories Ltd
10 Ladle brick. 'Newfields L'. British Steel Corporation
11 Ladle brick. 'Henllys'. British Steel Corporation
n.a. not available

advantages. The comparatively low alumina content (about 28 to 34 per cent) of ladle bricks is anomalous in that a relatively low-refractory brick is used in a high temperature environment. Ladle brick life is not, however, primarily related to refractoriness alone, but to a high bulk density, low porosity and, in certain varieties, a bloating property (up to 25 per cent volume) which seals the joints between adjacent bricks and prevents metal penetration. Bloating is caused by the entrapment of gases as softening takes place. In addition, a pyroplastic protective coating is formed on the surface of the brick, sealing the pores and producing a structure which is more resistant to slag and metal penetration. Fireclays for bloating ladle bricks should contain over 25 per cent Al_2O_3 and generally 2 to 2.5 per cent alkalis, to allow softening and bloating to take place, and a permanent volume expansion on reheating. Low porosity, low iron ladle bricks also have acid resistant properties and are sold for use in power station and cement plant chimneys. These are produced by firing ladle bricks at somewhat higher temperatures.

Steel is teemed (poured) into moulds through a nozzle in the base of the ladle. This is closed by a stopper fixed to steel rods which are protected from the molten steel by sleeves. The process is known as direct teeming. To improve the surface finish of the steel ingot, the molten steel may be introduced through a series of pipes into the base of the mould, a process called 'uphill teeming' or 'bottom teeming'. The sleeves, stoppers, pipes and nozzles, which are used only once, are known as holloware refractories and are mainly produced from fireclay containing at least 33 per cent alumina on a calcined basis, with preferably less than 3 per cent Fe_2O_3. Carbon should generally be less than 1.5 per cent to prevent black hearting. The clay should have a high thermal shock resistance and must not shrink, but soften and bloat in service to seal off joints and cracks.

The use of fireclay refractories in the casting pit, both in holloware and ladle bricks, is declining through the introduction of new technology and more severe operating conditions. One of the most important developments in steelmaking technology over the past 15 years has been the introduction of continuous casting, which eliminates the ingot casting, soaking pit and primary rolling stages, thus producing significant savings. Continuous casting, secondary steelmaking and other processes connected with the adjustment of steel quality require higher ladle temperatures and longer residence times, thus considerably increasing the severity of the environment in the steel ladle which can no longer be withstood by low cost firebrick. Consequently, higher alumina, bauxite and dolomite bricks are being increasingly used as alternatives. At present (1981) some 30 per cent of United Kingdom steel production is continuously cast and this is expected to increase to 60 to 65 per cent during the next two or three years. This growth will also have an effect on demand for holloware refractories used in uphill teeming, which formerly accounted for about half of their total market. The introduction of the sliding gate valve, operated from beneath the ladle, to replace the stopper rod assembly also eliminates the holloware sleeves that are used to protect it. All these factors will have a considerable effect on demand for fireclay and it seems inevitable that demand for fireclay ladle bricks will continue to decline. However, they represent a good, inexpensive lining and where ladle availability is not important and operating conditions not so severe, for example in foundries, they will continue to be used.

Elsewhere in the iron and steel industry the life of fireclay refractories is measured in years rather than hours, as is the case in casting pit refractories. Fireclay bricks of various qualities are used wherever operating temperatures are moderate. For example, they are widely used in the safety lining of vessels for the transfer of liquid iron or steel and in blastfurnaces.

Dense, aluminous, Scottish firebricks, typically with more than 42.5 per cent Al_2O_3, less than 1 per cent total alkalis and 2.5 per cent Fe_2O_3, were formerly used for lining the middle and upper stacks of blastfurnaces, but with the increasing size of blastfurnaces, firebricks have been replaced by flint clay and higher alumina bricks, all of which are based on imported raw materials. Flint clay bricks are stronger, denser and more abrasion resistant than Scottish firebricks. A low iron content is particularly important where firebricks operate in a reducing environment, as carbon monoxide severely attacks free iron and iron oxides and any iron present must be included in other phases. Calcined flint clay typically contains 43 per cent Al_2O_3, 0.5 per cent Fe_2O_3 and 0.5 per cent total alkalis.

The blast is heated in blastfurnace stoves, which until recently were almost entirely filled with a honeycomb mass of fireclay bricks ('chequer' bricks). The bricks are heated by the waste gases from the blast furnace and then air is subsequently heated by the hot bricks. Increased temperatures in blast furnace stoves have, however, led to silica bricks being used in the upper, hotter part of the stove, although 42 per cent Al_2O_3 firebricks are used in the middle and 32 to 36 per cent Al_2O_3 firebricks in the lower sections.

Fireclay bricks are also used in soaking pits and reheating furnaces and fireclay (< 35 per cent calcined) is also used in the production of certain coke oven refractories. Coke ovens call for complicated shapes, so that high dimensional accuracy is required, with high levels of grog added to offset firing shrinkage.

Whilst the use of formed fireclay bricks in the iron and steel industry is declining, there is an increasing demand for grog and chamottes (refractory clay specially fired) for use as either a non-plastic component in new bricks or for monolithic linings, that is, those rammed or cast into place. Grog and chamottes should be strong with low porosity (< 3 per cent) and graded to the required size specifications. The higher qualities, low in iron and alkalis, are made from Scottish fireclays. There is an increasing requirement for chamottes in castable or gunning form, for intermediate repairs on linings, for example, in blastfurnace stacks. Fireclays are also used in aluminous cements and other jointing materials and for producing lightweight refractory aggregates. Aluminous fireclays may also be used for bonding higher alumina bricks.

Fig 3 United Kingdom: Production of fireclay refractories (firebricks, shapes and holloware) 1945-1977. (Based on National Federation of Clay Industries' data.).

Demand for fireclay refractories has been declining for many years and particularly since the Second World War (Fig 3). The decline in iron and steel production in the United Kingdom has reduced demand for fireclay refractories, but technological changes within the industry and the trend towards higher operating temperatures have had a more pronounced effect. Iron and steelmaking is energy intensive and fuel savings can be made in two ways; by increasing throughputs and by insulation. Both put increasing demands on the refractories used, by raising temperatures to promote faster reaction times and reducing thermal gradients. The change from open hearth steelmaking (where firebricks were extensively used in the chequer chambers used to pre-heat air) to basic oxygen steelmaking has had a significant effect. Outside the iron and steel industry many of fireclay's traditional refractory uses, such as in the production of firebricks for domestic use, steam engines, ships boilers and the carbonising industry have virtually ceased.

The Business Statistics Office firebrick sales figures are somewhat larger than the corresponding figures collected by the National Federation of Clay Industries Ltd (which are no longer published), on which Fig 3 is based, probably because not all manufacturers are members of the Federation.

Table 2 United Kingdom: Sales of fireclay refractories, 1972-1980

	1972	*1973*	*1974*	*1975*	*1976*	*1977*	*1978*	*1979*	*1980*
					Thousand tonnes				
Firebricks and shapes (a)	513.0	555.2	580.1	474.0	462.5	411.7	351.6	377.2	239.7
Refractory holloware for casting pits (b)	110.3	123.5	120.7	110.5	112.9	101.3	100.0	109.9	77.5

Source: Business Stastistics Office

(a) Sales from firms employing 25 or more persons

(b) Believed to be mainly fireclay-based. (The Institute of Geological Sciences understands from discussions with industry that current annual sales of fireclay holloware are some 50,000-60,000 tonnes).

Fireclay refractories are relatively inexpensive and suitable for a range of applications where a higher quality refractory would be unnecessary. Demand for refractory fireclay will therefore ultimately stabilise, but there appears to be no agreement in the industry on either the level or timing of arrest in the decline. As a swing back to fireclay-based refractories is unlikely, a further reduction in the number of fireclay refractory manufacturers seems to be inevitable because of the current overcapacity in the industry.

Vitrified clay pipes

The mass production of dense, unglazed, vitrified clay pipes for sewage and surface water drainage and chemical effluents, and conduits for underground cable installations, is a relatively modern development, introduced on a large scale during the 1960s to replace salt-glazed pipes. These were originally produced from more siliceous Dorset ball clays, but subsequently fireclays, which possess similar properties, were used and production became concentrated on the coalfields, the local availability of fuel being an important economic factor. In 1953 there were over 80 separate salt-glazed pipe operations in the United Kingdom. Fireclays were found to be suitable since they were relatively plastic and could be easily extruded by the low pressure extrusion equipment then available. Moreover, being kaolinitic and refractory, they exhibited long vitrification ranges and were able to withstand the wide temperature variation in the circular downdraught kilns then used and minimised shrinkage and distortion of the pipes during firing. Since little vitrification took place, however, the body was porous and relatively weak, requiring the application of a salt-glaze to make it impermeable and thick walls to give the pipe adequate strength. Fairly high firing temperatures (about 1,200°C) were required to volatilise the salt and make it react with the clay to produce the glaze.

Introduction of de-airing, high pressure extrusion equipment after the Second World War reduced the need for a plastic clay and the benefits of a salt glaze were also questioned. A salt glaze tended to craze, rendering the pipe permeable and pollution problems associated with manufacture imposed further penalties. Salt glazing also damaged the linings of tunnel kilns, which were being introduced in greater numbers, and as a result use of the salt glazing process declined during the 1960s. Initially a ceramic glaze was used as an alternative, but eventually dense vitrification was adopted as a means of rendering the body of the pipe almost impermeable. Since vitrification also increased the strength of the body, the production of thinner walled pipes was possible. The introduction of tunnel kilns gave much better temperature control and the need for a refractory clay diminished, permitting use of clays with lower maturing temperatures and shorter vitrification ranges, thus allowing a much wider range of raw materials to be used. The use of continuous kilns and increasing automation in the industry has, however, necessitated precise characterisation of the clays by careful selection, quality control and large scale sophisticated blending, to provide clay feeds with predictable and consistent firing characteristics.

Vitrified clay pipes have to be highly resistant and durable to chemical attack, have very low water permeability and must be manufactured to close dimensional tolerances with sufficient strength to conform with B.S. 65:1981. The clays used should vitrify at between 1,000° and 1,100°C to produce a dense, impermeable product, but, as dimensional stability is critical, they should also exhibit an adequate vitrification range to prevent distortion and differential shrinkage during firing. The clays must also have sufficient green and dry strength to retain their shape after moulding (extrusion), and to allow handling after drying prior to firing. These properties are provided by a blend of clays, containing in broad terms roughly equal proportions of kaolinite, hydrous mica and quartz. This should not be considered as a unique composition for the production of vitrified clay pipes, however. Carbon levels should be less than 2 per cent, although the precise amount depends on the vitrification characteristics of the clay and the ease with which carbon can be burnt out. Because they are thinner than bricks and thus permit easier access of oxygen, pipe bodies can tolerate somewhat higher carbon levels. Where controlled, the production of a black, glassy phase in the body of the pipe can be used to advantage since it decreases the porosity of the body, thus reducing permeability and increasing strength. Excess carbon is the main reason for the rejection of a much wider range of clays many of which would have to be precalcined before use. Sulphur is a particularly deleterious impurity as when present as pyrite it acts as a powerful reducing agent and should normally be less than 0.2 per cent SO_3. A low carbonate content is also desirable. Fireclays are not, however, a prerequisite for the manufacture of vitrified clay pipes. Other mudstones with similar bulk mineralogies are utilised and it seems likely that a range of clays much wider than those currently used would be suitable.

The clay pipe industry has undergone a major rationalisation during the past 25 years through mergers and takeovers, and vitrified clay pipe production is now concentrated at two centres of roughly equal importance. In the Penistone district of South and West Yorkshire production is based primarily on Lower Coal Measures mudstones, unrelated to opencast coal mining, although some fireclays, mainly brought into the area, are used for blending to extend the vitrification range of the feed. The other major centre of production is in the South Derbyshire Coalfield, in the Swadlincote-Woodville area, where a range of fireclays are blended on a large scale. Minor production of vitrified clay pipes elsewhere is based on Coal Measures mudstones and fireclays, and on Etruria Marl.

Official statistics for vitrified clay pipe production were last recorded in 1973, when output amounted to 753,000 tonnes. Present consumption of clay for this purpose is probably of a similar order, of which more than half is fireclay. Any future increase in demand for vitrified clay pipes will depend on their ability to compete with pipes based on other materials, such as PVC, cast iron, pitchfibre and concrete, all of which are more energy intensive in their manufacture. Whilst clay pipes have tended to dominate the small diameter (up to 300 mm) pipe market, concrete has been the main raw material for larger diameter pipes. Vitrified clay pipes are now produced in diameters up to 1 m and, in view of their superior acid resistance properties, they may prove to be highly competitive with concrete pipes in some environments.

Agricultural land drain production in the United Kingdom is based on a wide variety of clays, fireclays being used only at a few operations, mainly to extend the vitrification range of the feed.

Facing bricks

Fireclays, because of their comparatively low iron and somewhat higher alumina contents compared with most other brickmaking clays, are used in the manufacture of near-white to buff facing bricks. Although buff bricks were produced from fireclays before the Second World War, quality buff facing bricks became available only after the War. In recent years demand has increased for near-white to buff facing bricks, and architects are also demanding a uniform colour throughout the body of the brick which will not be affected by weathering or chipping. Unless expensive chemical additives are used to modify the fired colour of a clay, the brickmaker is dependent on their natural fired colour. Both colour and texture are important factors in marketing.

With the exception of the Tertiary ball clays of Devon and Dorset, which are for the most part too expensive to be used for brickmaking, only two varieties of inherently near-white to buff-firing brick clays are produced in the United Kingdom; highly calcareous clays, such as parts of the 'Keuper Marl' now Mercian Mudstone, which are light-firing due to the bleaching action of lime on ferric oxide, and certain fireclays. Where durability is important however, fireclay is the much preferred raw material, producing a stronger brick with a lower water absorption. Compressive strengths for facing bricks manufactured from fireclays are generally in the range 67 to $76 MN/m^2$, with water absorptions in the range 4.7 to 9.9 per cent.

Fired colour is the basic criterion on which the suitability of a fireclay is judged, comparatively few having the desired colour. Iron oxide should be less than 2.5 to 3 per cent and, on firing, the fireclay should give a uniform colour throughout. Near-white firing fireclays are suitable for blending with red-firing mudstones to give a range of colours; chemical additives, such as manganese dioxide which produces a grey colour, can also be introduced. Fireclays are also blended with red-firing mudstones to produce a range of colours in the manufacture of vitreous floor tiles and such building products as air bricks, roof ridges and chimney pots. Carbonaceous matter in fireclays can be a serious impurity. The introduction of fast firing tunnel kilns has necessiated low carbon levels which should usually be kept below 1.5 per cent, although up to 2.5 per cent can be tolerated in some clays depending on firing conditions and the ease with which carbon can be burnt out. Typically, fireclays used in buff brick manufacture have alumina contents in the range 20 to 30 per cent. A higher alumina content is a disadvantage as higher firing temperatures are required to produce the desired vitrification which can significantly add to costs. Many brick kilns are also not designed to withstand high firing temperatures. Normally the alumina and alkali contents of the fireclay should be consistent with vitrification occurring at normal brick-firing temperatures, i.e., 1,040 to 1,080°C, to give the desired strength and water absorption, although maturing temperatures of 1,100 to 1,140°C are utilised at some brick works, and temperatures over 1,200°C have been reported.

A few brickworks with associated quarries exploiting Coal Measures mudstones have captive sources of supply, but most fireclays for buff brick manufacture are obtained from the opencast coal and fireclay mines and are sometimes transported for distances of up to 160 km. Transport costs can therefore be a very significant proportion of the delivered price and fireclays are an expensive brickmaking raw material, typical delivered prices being in the range of £2.50 to £7.00 a tonne in 1980. Present consumption of fireclays for buff brick manufacture is estimated at about 300,000 tonnes a year, representing a very small proportion of total brick clay production but a significant part of total fireclay output. However, at individual brickworks production of buff bricks may represent a significant proportion of total output and the opencast coal industry will continue to be an important source of fireclay for this industry.

Pottery

Despite their similar bulk mineralogies, fireclays are neither as plastic nor as white-firing and consistent as ball clays and are therefore not used in the manufacture of whiteware ceramics (pottery with a white body such as tableware, vitreous sanitaryware and most wall tiles). Ball clays are valued because of their plasticity and high strength, which facilitate the shaping and handling of the unfired body, their white or near-white firing characteristics, the presence of mica which contributes to vitrification during firing, and their rheological properties, which are important during slipcasting.

Selective mining and blending of ball clays with detailed quality control have allowed consistent grades to be produced. Some relatively plastic and near-white firing fireclays may have properties similar to low-grade ball clays and, at least in theory, could in part replace more expensive ball clay in certain sectors of the whiteware ceramics industry. However, their variable quality and mode of occurrence are major obstacles to the production of an acceptable product.

In the pottery industry, fireclay is currently used in the manufacture of fireclay sanitaryware, stoneware and some floor and wall tiles. Sanitaryware is produced from two different types of body—vitreous china, a typical whiteware body, composed of china clay, ball clay, flux and silica, and sanitary fireclay made entirely from fireclay and fireclay grog, both products being produced by slip-casting. Since fireclay is not white-firing the ware is covered with a white burning body, known as an engobe, and a glaze. During slip casting a thick lining of clay is allowed to be built up giving a much heavier, stronger body than with vitreous china sanitaryware. Production of fireclay for this purpose has declined, but appears to have stabilised at perhaps about 20,000 tonnes a year.

Stoneware is hard, dense and impermeable, usually with a buff or ivory colour, and is often covered with a coloured or opacified glaze. It is used in some tableware, kitchen and decorative ware and is much valued by studio potters. Certain fireclays are suitable as stoneware clays as they vitrify at stoneware temperatures (1,200 to 1,250°C) to give a low porosity, buff to ivory coloured body, sufficiently plastic for hand and machine forming. The coefficient of thermal expansion of the clay is critical; it should be slightly higher than that of the glaze so that as the glaze contracts less it is kept under compression, thereby making it stronger. Because of their thermal expansion properties, siliceous fireclays are utilised in stoneware manufacture, a typical composition being: 60 to 61 per cent SiO_2; 1 per cent TiO_2; 23 to 24 per cent Al_2O_3; 2 per cent Fe_2O_3; 0.2 per cent CaO; 1 per cent MgO; 3.5 per cent K_2O; 0.2 per cent Na_2O and 7 per cent loss on ignition.

The large, wall tile industry in the United Kingdom utilises white-firing, plastic and semi-plastic ball clays and china clay as the main clay raw materials. Only limited amounts of fireclay are used in the production of a glazed tile body used as both a wall and floor tile.

Other uses

At present, fireclay has limited non-ceramic applications. Ground fireclay is used as an alternative to ball clay in binding animal feedstuffs and small quantities are used as a filler/binder in the production of horticulural fertilisers. Fireclay may also be used as a 'puddle clay' for lining canals.

Future uses

There appears to be little likelihood of future growth in demand for fireclay in its traditional applications in the manufacture of refractories. The use of fireclay in the manufacture of buff facing bricks has been the only sector to show growth in recent years and continuing growth will depend on future aesthetic preferences. However the wide range of compositions and properties shown by fireclays, their low price and availability, offer considerable incentive to explore new markets for the mineral, both in and outside the ceramics industry.

There are several possibilities particularly if a more consistent product could be made available by effective quality control and blending. Certain fireclays might replace some of the more expensive ball clay used in wall tiles. Ball clay constitutes some 35 to 40 per cent of the wall tile body, acting as a binder to the dust pressed tile and, being vitreous, contributing to the fired strength (the china clay acts primarily as a white filler). Since wall tiles have to be produced to a high dimensional accuracy, the body must possess very low and consistent contraction rates. United Kingdom consumption of ball clay by the wall tile industry is some 100,000 tonnes a year and a partial replacement of this tonnage might be feasible, although in terms of total fireclay output, the market cannot be considered large. Nonetheless, it could be an important development, particularly in view of the proximity of the market to potential fireclay sources. However, the occurrence of fireclays with properties akin to ball clays appears to be limited. The Applied Mineralogy Unit of the Institute of Geological Sciences has examined a few fireclays, mainly from the South Staffordshire Coalfield, and shown them to be similar to some ball clays in terms of their composition, plasticity and firing behaviour, although they do not exhibit the same white to off-white fired colours normally associated with ball clays. The successful use of fireclays as possible alternatives to ball clays in wall and floor tile manufacture would necessitate production of consistent grades.

Clays, particularly kaolinite-rich clays with their higher alumina content, have long generated interest as an alternative to bauxite as a source of alumina, primarily for aluminium production, but also for refractory purposes. Of the various processes suggested for alumina production from clays, acid leaching is currently considered one of the most attractive. Large reserves of high alumina clay (more than 10 million tonnes of contained alumina), with low alkalis and iron amenable to opencast mining, would be needed. Kaolinite-rich clays in the United Kingdom are represented by china clay (kaolin), ball clay and fireclay; some mudstone and colliery waste, with lower alumina contents, have also been considered, as have micaceous residues from the china clay industry. The high value of china clay and ball clay make it unlikely that they would be used, unless perhaps of inferior quality, but fireclays represent a very large indigenous alumina resource, potentially available at relatively low cost as a by-product of opencast coal mining. The maximum solubility of kaolinite by mineral acids is achieved in the metakaolinite (Al_2Si_2O) state following dehydroxylation of kaolinite at about 600°C. Above 900°C metakaolinite changes to silicon spinel and subsequently mullite, which are significantly less reactive chemically. For the production of metakaolinite, a thermal pretreatment stage is required and carbon, normally present in fireclays as coal, would be beneficial (providing temperatures can be controlled) since it would contribute to the energy requirement. Iron is a serious impurity since it would go into solution and require subsequent removal, while alkalis would consume acid. If all current United Kingdom alumina requirements, approximately 0.9 million tonnes, were to be met from indigenous fireclay, production of the mineral would have to be increased by about 3 million tonnes a year. Such quantities could be recovered from opencast coal mines (1.0 million tonnes of fireclay are currently being produced annually from one operation in the South Derbyshire Coalfield).

The Ayrshire Bauxitic Clay, a hard, dense, non-plastic seat clay consisting predominantly of kaolinite, was used as a source of alumina for the manufacture of aluminium sulphate [$Al_2(SO_4)_3.18H_2O$] during the period between the First World War and 1979. Production is now based on Bayer alumina. Aluminium sulphate is used mainly in the paper industry for the clarification of process water and as a setting agent in sizing and dyeing paper, and in water and sewage treatment.

The crushed clay was initially calcined at 500 to 600°C, the high carbon content of some of the clay producing a self-calcining blend. Alumina extraction was carried out by counter current sulphuric acid dissolution, recovery being some 80 to 90 per cent. The advantage of the Ayrshire Bauxitic Clay was not only its high alumina content (32 to 38 per cent, uncalcined), but also its low alkali content (0.5 per cent $K_2O + Na_2O$); the presence of excessive amounts of potassium caused problems in the evaporation process with the formation of insoluble products in the final aluminium sulphate. Iron was also a serious impurity and had to be kept below 1.5 per cent Fe_2O_3 in the raw feed. Fireclays were considered as possible sources of alumina to replace the Ayrshire Bauxitic Clay, but their higher iron contents and, particularly, higher alkalis made them unsuitable.

In the United Kingdom the use in ironmaking of imported high grade iron ores with low levels of impurities necessitates introduction of silica to the blastfurnace burden to form sufficient slag, the principal function of which is to remove sulphur. Alumina is also required for slag formation and is usually introduced in aluminous iron ores. Some aluminous iron ores have the disadvantage of a high alkali content, which can give rise to refractory attack and poor furnace productivity. The possible use of low alkali, high alumina fireclay as a source of both alumina and silica has, therefore, been considered. Impurities such as iron and carbon, normally regarded as deleterious, would present no difficulties.

Resources

Seatclays, and thus fireclays, are closely associated with coal and are principally found in the Westphalian (Coal Measures), the major coal-bearing stage in the United Kingdom. Seatclays associated with other Carboniferous coals, the Limestone Coal Group (early Namurian) in Scotland and the Scremerston Coal Group (Dinantian) of Northumberland, have been little used as commercial fireclays and information on their quality is generally not available. The humid, tropical climatic conditions, which favoured the formation of coal forests, also favoured the formation of kaolinite, a major component of most fireclays. These conditions also existed during Namurian times in central Scotland, as evidenced by the Aryshire Bauxitic Clay, and also the thick, economically important aluminous fireclays of the Passage Group. Kaolinite-rich fireclays appear to be more prevalent in early Upper Carboniferous sediments (Namurian-Westphalian A) suggesting that climatic conditions were then more favourable to intense weathering. However there are important exceptions, for example, the kaolinite-rich fireclays of the South Derbyshire Coalfield are of Westphalian B (Middle Coal Measures) age. The grey measures of the ealier Westphalian stages give way to 'red bed facies' indicating climatic changes and the onset of more arid and oxidising conditions.

Tropical climatic conditions have existed at other times in the geological history of the United Kingdom. Those which occurred during Eocene-Oligocene times gave rise to the economically very important kaolinitic ball clays of Devon and Dorset which can be considered as less indurated, more plastic, analogues of Carboniferous fireclays (*see* Mineral Dossier No. 11 in this series). Similar depositional environments also existed during the Middle Jurassic and gave rise to siliceous fireclays, which are worked in the Midlands on a limited scale for refractory purposes. Mudstones with many of the characteristics of seatclays, being generally kaolinitic in composition and exhibiting refractory properties, are also developed in the Ashdown Beds of Lower Cretaceous age in the Hastings area.

Upper Carboniferous

With the exception of those of Namurian age in central Scotland, economically important fireclays are almost entirely confined to the Lower and Middle Coal Measures. The classification of the Upper Carboniferous in Britain is shown in Fig 4. A characteristic feature of the sediments is their pronounced cyclicity, usually with a seatearth in each cycle. Seatearths of varied thicknesses and compositions occur at irregular intervals and are widely distributed. Fireclays were produced from virtually all the coalfields of Britain until the early 1960s and most seatclays warrant examination as potential fireclays.

Scotland

The fireclays of the Midland Valley of Scotland have a high reputation for quality and include the highest alumina and most refractory fireclays produced in the United Kingdom. The Carboniferous succession in the Midland Valley is shown below.

Upper Carboniferous	Upper Coal Measures Middle Coal Measures Lower Coal Measures Passage Group Upper Limestone Group Limestone Coal Group
Lower Carboniferous	Lower Limestone Group Calciferous Sandstone Measures

Economically important coals have a wider stratigraphical distribution in Scotland than in England and Wales (*see* Fig 5) and reach their maximum development in the Limestone Coal Group and the Lower and Middle Coal Measures. Coals also occur within other subdivisions of the Carboniferous but, except for those within the Upper Limestone Group, are of little economic significance. Consequently seatclays also have a wider stratigraphical distribution than elsewhere and fireclays are produced from the Passage Group as well as from the Lower Coal Measures.

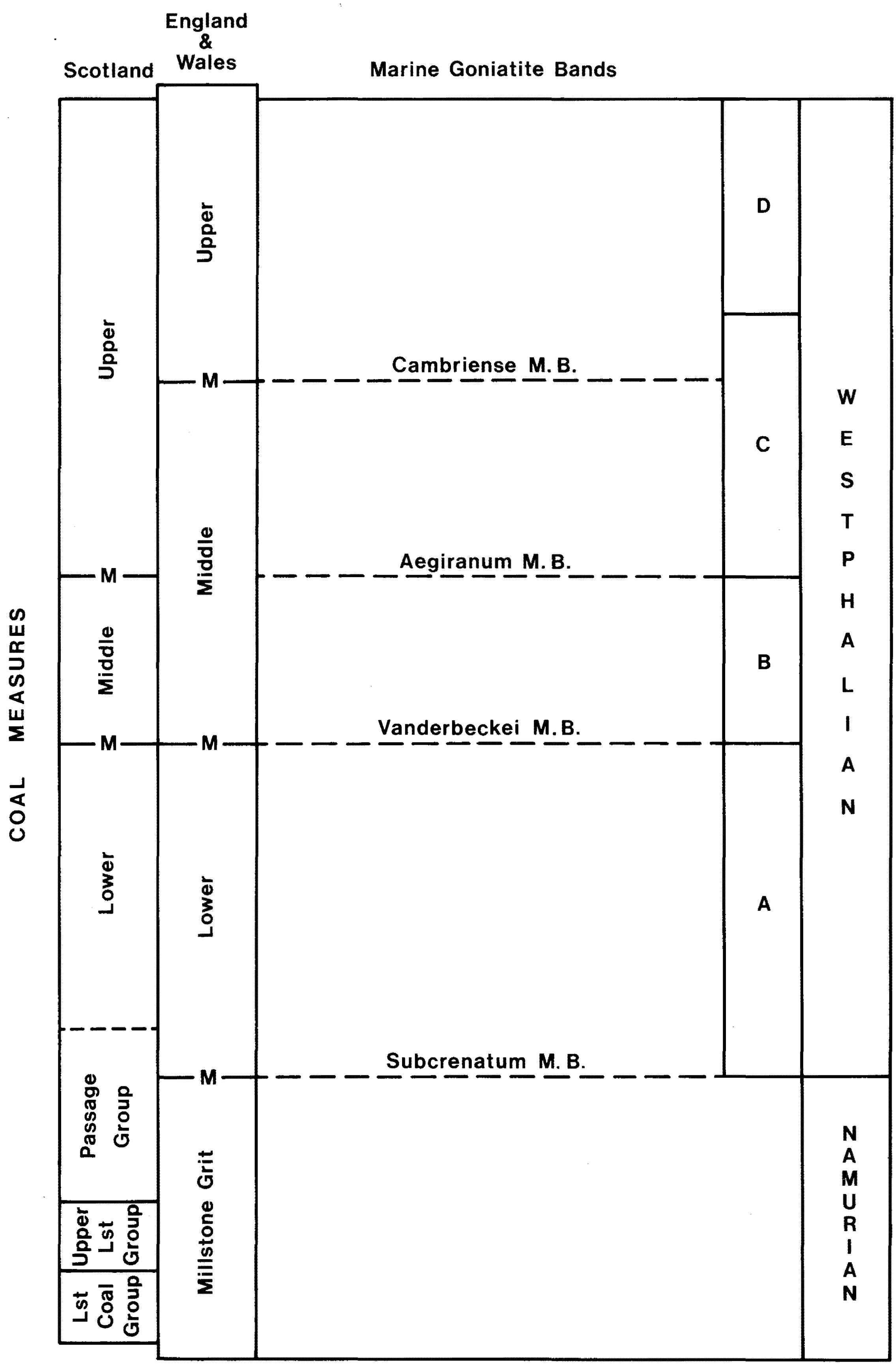

Fig 4 **Classification of the Upper Carboniferous in Great Britain. (Based on: A correlation of Silesian rocks in the British Isles. W. H. C. Ramsbottom *et al.,* 1978.)**

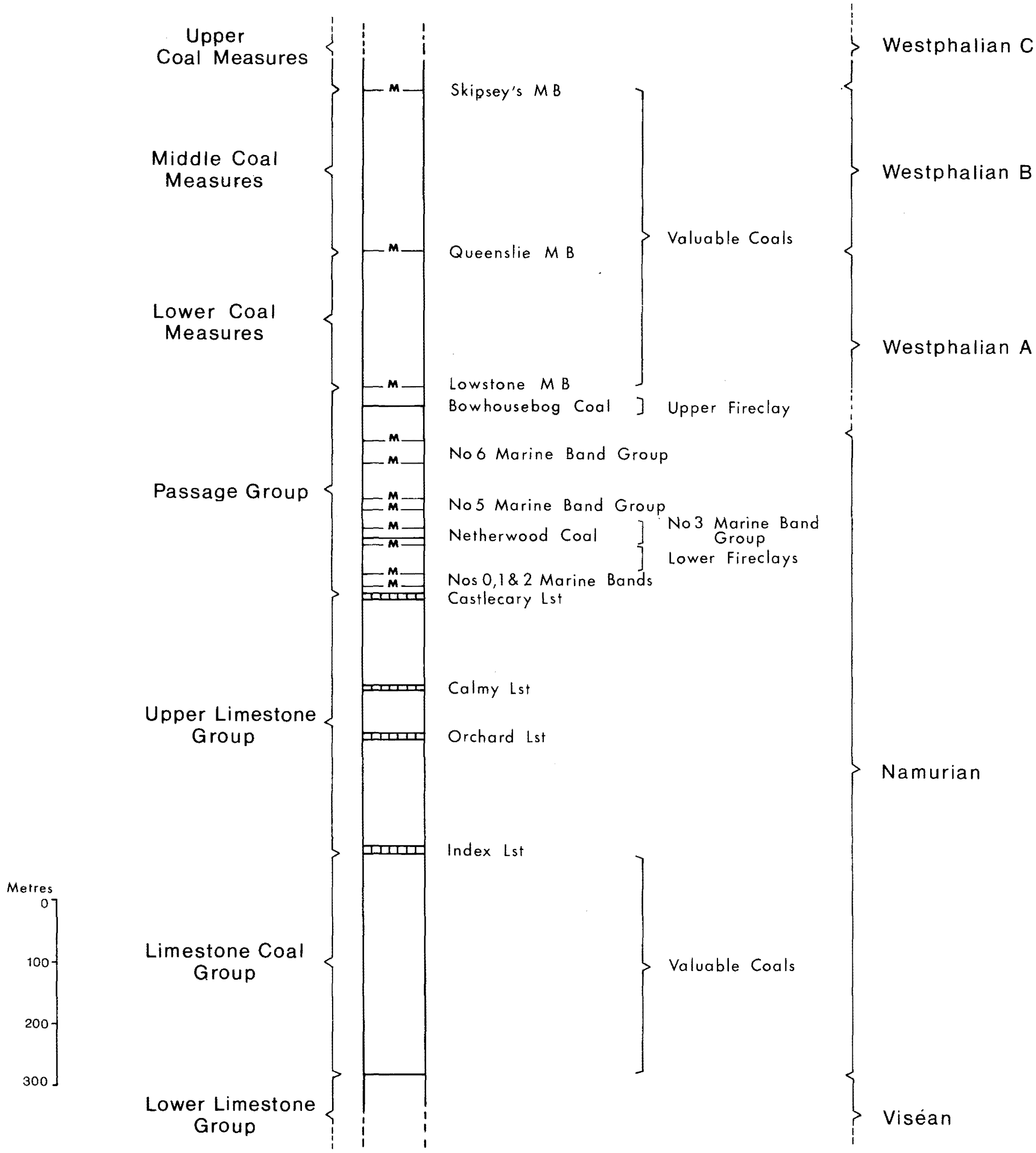

Fig 5 Generalised Carboniferous succession in céntral Scotland showing the stratigraphical position of the Passage Group in relation to economically important coal-bearing strata.

Fireclays within the Calciferous Sandstone Measures were formerly produced in the Paisley district and a seatclay with 32 per cent Al_2O_3 (uncalcined) has been encountered in a borehole at Milngavie, north of Glasgow, in the same formation. Seatearths within the Limestone Coal Group tend to be poorly developed and sandy and, whilst they have been exploited in the past, mainly for non-refractory applications, none is currently recovered despite extensive opencast coal mining activity. Comprehensive data on their physicochemical properties are not available.

The Passage Group, consisting of the strata between the top of the Castlecary Limestone and the local base of the Coal Measures, is equivalent to parts of the Millstone Grit and Lower Coal Measures in England and Wales (*see* Fig 4), and is the source of the most valuable refractory fireclays produced in the United Kingdom. The Passage Group is dominantly arenaceous, containing massive, often whitish-grey, sandstones some of which are quartz-rich and valued as sources of silica sand. Except in the small Westfield Basin of Fife, where abnormally thick sequences of coal occur, the Passage Group contains only rare thin coal seams and is therefore of little interest to the opencast coal mining industry. Fireclay extraction has, until recently, been predominantly by underground mining, although because of high mining costs there is increasing interest in opencast working.

Within the Central Coalfield, the most important producing area, the fireclays are concentrated towards the base and top of the Passage Group. The Lower Fireclays, which occur between the No. 2 Marine Band (Roman Cement) and the Netherwood Coal in the lower part of the Passage Group, are, because of their high alumina contents (42 per cent calcined), economically the most important. They consist of a number of thick seams which are probably not individually persistent on a regional scale. The Upper Fireclay, which occurs near the top of the Pasage Group immediately above and below the Bowhousebog Coal, typically has a lower alumina content (37 per cent Al_2O_3 calcined) and, although mined

Table 3 Typical chemical analyses of Scottish fireclays

	Wt %						
	1	2	3	4	5	6	7
SiO_2	52.05	51.62	57.09	n.a.	52.19	52.21	51.6
Al_2O_3	43.39	43.39	37.02	42.5-43.8	42.52	42.49	43.2
Fe_2O_3	1.79	2.30	2.40	2.0-2.7	2.36	2.58	2.46
CaO	0.22	0.28	0.32	n.a.	0.19	0.50	0.38
MgO	0.41	0.44	0.58	n.a.	0.41	Trace	0.24
Na_2O	0.05	0.13	0.12	0.3-1.5 (Na₂O + K₂O)	0.05	0.09	0.07
K_2O	0.29	0.35	0.84		0.68	0.06	0.35
TiO_2	1.17	1.46	1.58	n.a.	1.44	2.05	1.23

Source: 1 Lower Fireclays (calcined). Passage Group. Ballencrief mine. The Burn Fireclay Co Ltd.
2 Lower Fireclays (calcined). Passage Group. Pottishaw mine. United Fireclay Products Ltd.
3 Upper Fireclay (calcined). Passage Group. Tippethill mine. United Fireclay Products Ltd.
4 Lower Fireclays (calcined). Passage Group. Whitrigg mine. Dyson Refractories Ltd.
5 Fireclay above Crofthead Slatyband Ironstone Coal. Passage Group. Roughcastle mine. Dyson Refractories Ltd.
6 Fireclay (calcined). Passage Group. Monkcastle mine. A.P. Green Refractories Ltd.
7 Lower Fireclays (calcined). Passage Group. GR-Stein Refractories Ltd.

n.a. not available

until comparatively recently, is no longer worked. Being associated with a coal seam it also tends to have a high carbon content. The precise base of the Lower Coal Measures (Westphalian A) cannot be defined accurately in Scotland but within the Central Coalfield the local base is taken at the Lowstone Marine Band. Fireclays associated with the Crofthead Slatyband Ironstone Coal, at the top of the Passage Group, also exhibit high alumina contents (40 per cent, calcined) and they have been mined at Roughcastle near Bonnybridge and quarried near Slammanan.

The fireclays of the Passage Group consist of unbedded mudstones, with or without rootlets, and may be up to 5 m to 6 m thick. Usually, only 2.5 to 3 m is worked by underground mining, but where the bed is thick, up to 5 m may be extracted. They are usually grey or dark brown, are sometimes mottled red or lilac, and are hard, dense and semi-plastic. The Lower Fireclays typically have no associated coals, but are the clay-rich fraction of a sequence that becomes fine-grained upwards separated by erosion surfaces from massive sandstones. They are thought to represent the overbank deposits laid down on the flood plain of a meandering river system. The fireclays consist predominantly of poorly crystallised kaolinite and are thought to have been derived from a local source area undergoing tropical weathering.

Originally, the Scottish firebrick industry was based on the Lower Fireclays of the western outcrop of the Passage Group in the Central Coalfield, particularly in the Glenboig district, but the Lower Fireclays were subsequently found to be of a higher quality on the eastern outcrop, and production is now concentrated in this area. The distribution of fireclay workings in the Central Coalfield is shown in Fig 6. Aluminous fireclays, some containing over 40 per cent Al_2O_3 (calcined), have also been found by the Institute of Geological Sciences in boreholes at comparable horizons within the Passage Group of the Clackmannan Syncline. Within the Fife-Midlothian Basin to the east, the presence of refractory fireclays is not known, but mudstones are concentrated in the middle of the Passage Group rather than near the top and base as in the Central Coalfield. The fireclay potential of the Westfield Basin in Fife, where a large scale opencast coal mine exploits coals within the Passage Group, does not appear to have been assessed.

The conditions which gave rise to the high quality fireclays of the Passage Group persisted and several coal seams towards the base of the Lower Coal Measures in the Central Coalfield have thick, aluminous fireclays associated with them. Fireclays are extracted with coal and sometimes blaes (carbonaceous mudstone used in brick manufacture) in licensed opencast coal mines: the fireclay (36 to 38 per cent Al_2O_3, calcined) under the Balmoral Coal (equivalent to the Armadale Ball Coal) was mined underground near Glenboig until 1980. A significant number of fireclays up to at least the Upper Drumgray Coal have been worked in the past, the higher qualities being associated with the Armadale Main, Armadale Ball and Mill coals. Although the fireclays near the base of the Coal Measures contain up to 40 to 42 per cent Al_2O_3 (calcined), they appear not to be as consistent as those within the Lower Fireclays of the Passage Group, tending to have somewhat variable carbon, sulphur and iron contents. Nevertheless, these fireclays represent an important source of supply and, because of the trend towards opencast mining, have the added economic advantage of being extracted in association with coal. At Roughcastle, to the west of Falkirk, opencast working of the Glenfuir 'A', 'B' and 'C' fireclays commenced in 1980. The fireclays occur below a thin unnamed coal some 5 m below the Glenfuir Coal (equivalent to the Armadale Main Coal) and 1 m below the locally developed Under Glenfuir Coal, which has an associated lower quality fireclay. They have alumina contents (calcined) in the range 40 to 42.5 per cent with less than 2 per cent Fe_2O_3 and range between 0.3 m and 1 m in thickness separated by sandstone or more siliceous fireclay beds up to 1 m thick. The lowest workable coal of any importance in the Central Coalfield is the Colinburn Coal, although exploration is being extended down to the Crofthead Slatyband Ironstone Coal at the top of the Passage Group (*see* Fig 7). Seatclays towards the

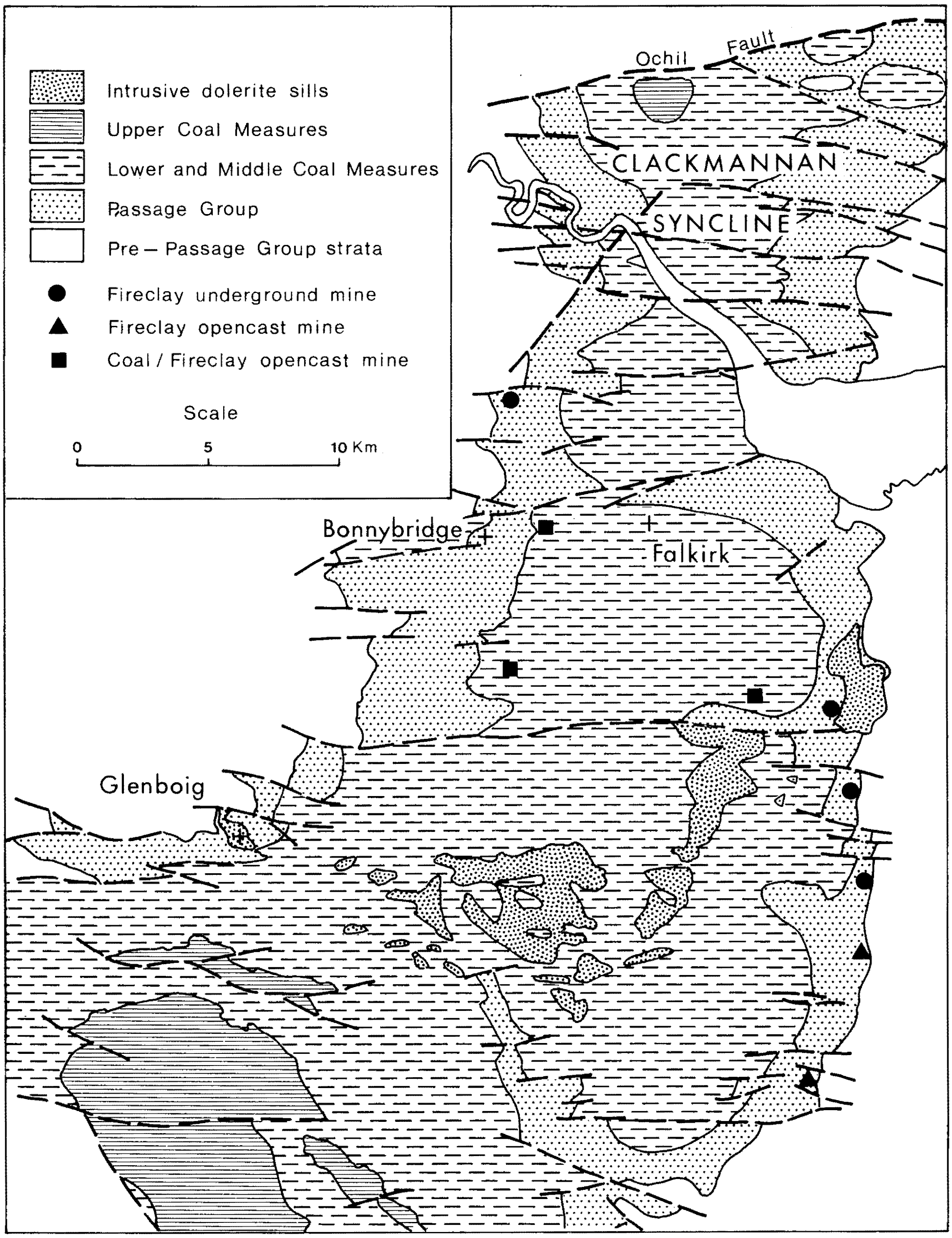

Fig 6 Distribution of fireclay workings in the Central Coalfield of Scotland.

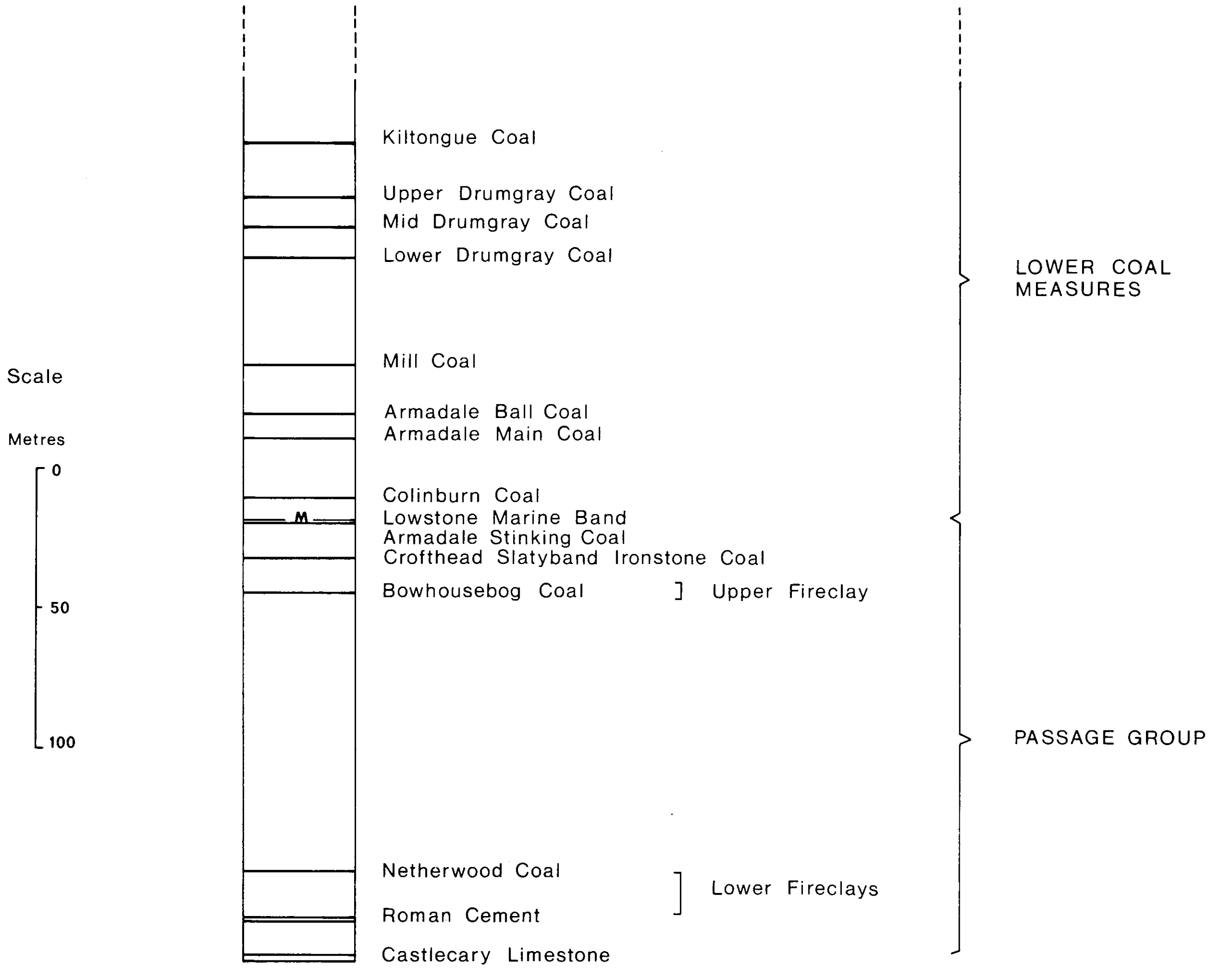

Fig 7 Stratigraphy of the Passage Group and Lower Coal Measures of the Central Coalfield. (*Source:* North Lowlands Unit, Institute of Geological Sciences).

base of the Lower Coal Measures warrant examination as potential fireclays and the NCB's Headlesscross opencast mine near Shotts, working the sequence between the Colinburn and Mill coals, would appear to offer some potential. The main factors, other than alumina content, which may make these seatclays unacceptable are their carbon and iron impurities.

The Passage Group of Ayrshire consists of three formations: the Ayrshire Bauxitic Clay Formation, the Passage Group Volcanic Formation, consisting mainly of basaltic lavas with some intercalated sediments, and a basal sedimentary formation which has not been formally defined. A high quality fireclay, locally developed in the lower sedimentary formation, was mined underground for many years until 1981 at Monkcastle, near Dalry, and used locally in the manufacture of 40 to 42 per cent Al_2O_3 firebricks. The fireclay, which consists of a hard, grey, semi-plastic seatclay, is up to 4 m thick but only a 2 m section was extracted. Contemporaneous tropical weathering of the basaltic lavas within the Passage Group before Coal Measures sedimentation began resulted in the formation of the Ayrshire Bauxitic Clay, a hard, dense, non-plastic seatclay of flint clay character, which typically exhibits a conchoidal fracture. The clay crops out along the northern edge of the Ayrshire Coalfield from Saltcoats on the coast eastwards to the Fenwick Water north of Kilmarnock. The clay also occurs in faulted outliers to the south of the main outcrop and clays of similar character have been recognised at about the same horizon near Stranraer, in the Sanquhar Basin, in Kintyre and on Arran. The bauxitic character of the clay was indicated by analysis of material exposed on the seashore at Saltcoats, which contained 47.57 per cent Al_2O_3 and in which boehmite and diaspore were identified. However, the clay is composed mainly of moderately well-ordered kaolinite with variable amounts of carbon and sphaerosiderite, and has been shown to have a mean TiO_2 content of 4.68 per cent.

The clay has a variable thickness, but is some 1.5 m to 2 m thick on average and can be seen to pass down into unaltered basalt. North of the Dusk Water Fault, which was active during sedimentation, the formation can be up to 20 m in thickness and includes intercalated coals. Initial interest in the clay was as a refractory raw material, but since the First World War it has been used mainly as a source of alumina for the manufacture of aluminium sulphate. The clay was formerly worked for this purpose by both underground and opencast mining. Mining ceased in the mid-1960s and the last opencast workings to the south and north-east of Kilwinning were abandoned in 1979. Minor quantities are used in the production of chamotte, but the Ayrshire Bauxitic Clay has a significantly higher iron content than commercial flint clays. Analyses of light brownish grey Ayrshire Bauxitic Clay from the Dubbs quarry near Stevenston are shown in Table 4. The clay has a higher iron content than might have been expected for material used in aluminium sulphate manufacture.

Table 4 Chemical analyses of Ayrshire Bauxitic Clay

	Wt %	
	1	*2*
SiO_2	46.2	46.5
Al_2O_3	42.0	40.6
Fe_2O_3	4.93	3.45
CaO	0.46	0.57
MgO	0.35	0.27
Na_2O	0.17	0.18
K_2O	0.12	0.10
TiO_2	5.75	7.57
	99.98	99.24
Loss on ignition	15.00	14.20

1 and 2 Dubbs quarry (NS 282424), Stevenston. Strathclyde. X-ray spectrometry (Betaprobe) of ignited samples

Analyst: A.E. Davies. Analytical Chemistry Unit, Institute of Geological Sciences.

High alumina fireclays have been identified in the Douglas Coalfield, a small Carboniferous outlier occupying the valley of the Douglas Water to the south of the Central Coalfield. During the late 1950s a fireclay within the Passage Group in the vicinity of Poniel was examined as a potential source of alumina for the production of aluminium sulphate. The fireclay had a calcined alumina content of about 42.5 and contained less than 2 per cent Fe_2O_3. Large reserves were proved, but no production ultimately took place. Recently, high alumina fireclays have been identified within the Upper Limestone Group of the Douglas Coalfield.

West Cumbria Coalfield

The Coal Measures occur on the north-west, north and north-east flanks of the Lake District, the productive coal seams being confined to the Lower and Middle Coal Measures which have a maximum thickness of 450 m. Parts of the Coal Measures have been affected by oxidation in an arid environment, caused by their uplift above the water table in pre-Permian times. This has caused reddening, due to the oxidation of ferrous iron to ferric oxide, and has also totally removed carbon, including coal seams. The zone of alteration extends to variable depths, being above the St. Helens Marine Band near the coast, but along the northern outcrop, east of Dearham, the base is maintained a short distance above the Ten Quarters Coal. East of Caldbeck the whole Coal Measures succession is reddened and the coals destroyed.

A small number of fireclays, including the seatclays to the Little Main and Brassey coals, have been worked, but for many years production was largely confined to the Micklam Fireclay Seam which, with a calcined alumina content of 40 per cent, is perhaps the highest quality fireclay occurring in England and Wales. The fireclay is 0.75 m thick and forms the seatclay to the Lower Three Quarters Coal near the base of the Lower Coal Measures (Fig 8).

Table 5 Typical analyses of the Micklam Fireclay

	wt %	
	1	2
SiO_2	45.44	52.53
Al_2O_3	35.50	41.04
Fe_2O_3	1.79	2.07
CaO	0.42	0.48
MgO	0.72	0.87
Na_2O	0.12	0.14
K_2O	1.66	1.92
TiO_2	0.85	0.98
Loss on ignition	13.50	—

Source: 1 Micklam Fireclay (dry basis). British Steel Corporation
2 Micklam Fireclay (calcined). British Steel Corporation

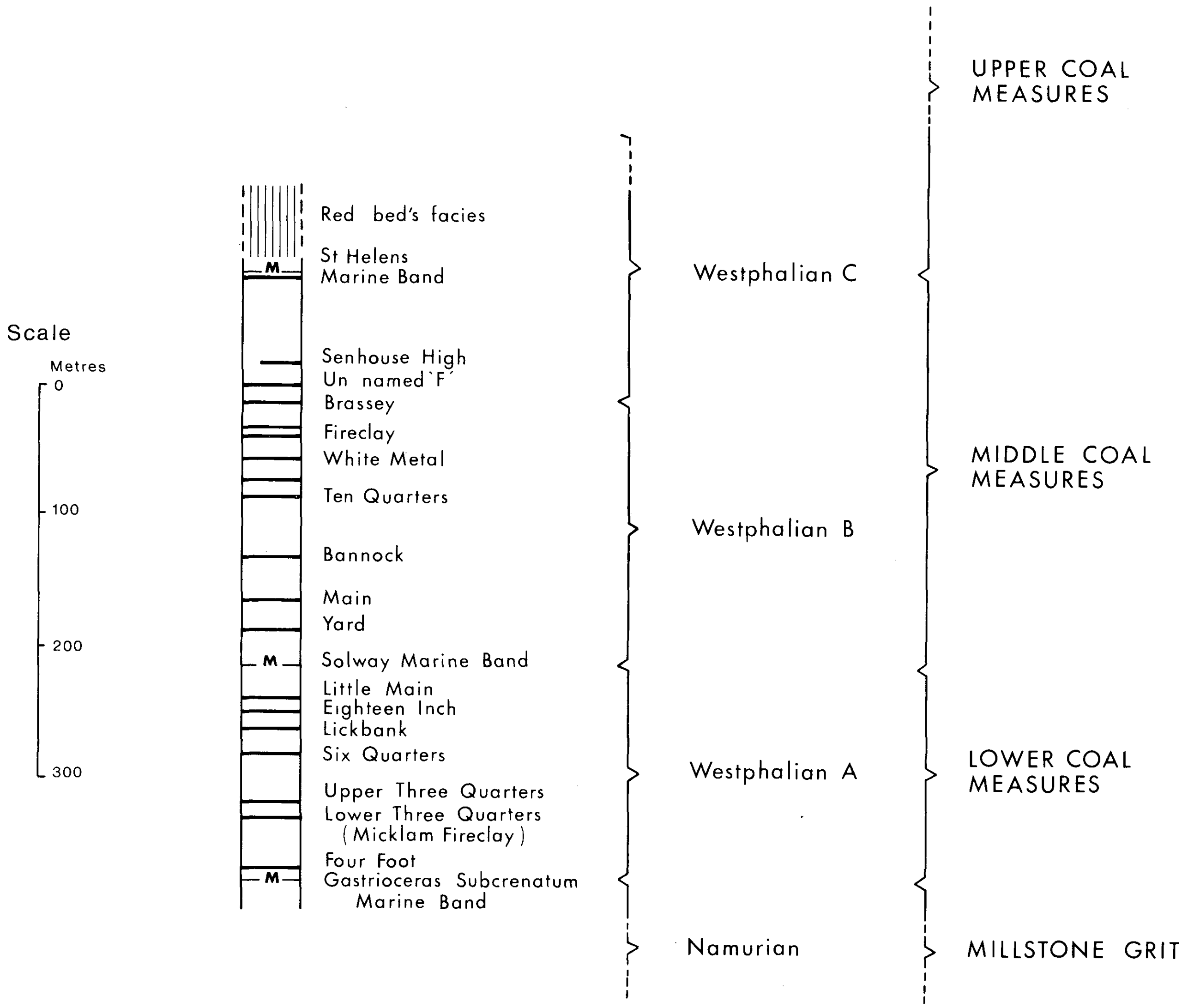

Fig 8 Coal Measures succession in the West Cumbria Coalfield. Based on B. J. Taylor. *In*: The Geology of the Lake District, 1978).

Both the fireclay and the coal were mined underground, by pillar and stall methods, from the Micklam No. 5 mine situated some 6.5 km south of Workington. Until 1969 2 m of the mudstone overlying the coal was also mined for brickmaking. The mine was closed in March 1981 because of high mining costs.

Limited quantities of coal have been extracted by opencast mining since the late 1950s and production has only recently increased significantly. The Opencast Executive aims to sustain production of 1 million tonnes a year and there are thought to be sufficient reserves for output to be continued at this level until at least the year 2000. Partial analyses of fireclays undertaken by the NCB on promising borehole samples exhibit variable alumina contents, many of which are in the range 26 to 29 per cent (calcined), while some contain over 30 per cent with low iron (3 per cent Fe_2O_3); these included the Lickbank (33.6 per cent), Top Eighteen

Inch (35 per cent), Brassey (33 per cent) and the Un-named 'F' (Clifton Moor 'F' 35 per cent). Only very limited quantities of fireclay from the Six Quarters have been produced from opencast coal mines in the County (*see* Table 23), including some brick clay. The area is remote from major centres of demand and there is only a small local market. Material comparable to the high quality Micklam Fireclay has not been identified within opencast coal mines and refractory production at the British Steel Corporation's Micklam works is now based on Scottish aluminous fireclay.

Northumberland and Durham Coalfield

Historically, the Northumberland and Durham Coalfield has been one of the most important sources of fireclay in the United Kingdom for the manufacture of refractories, salt-glazed sanitaryware and, more recently, buff facing bricks. Fireclay has been obtained mainly from the Lower Coal Measures, but small quantities have also been mined from the Millstone Grit of the Corbridge and Hexham areas for use in the manufacture of salt-glazed ware. Fireclay production was formerly much greater than at present; returns, for example, made to the Mining Record Office in 1876 amounted to 765,000 tonnes compared with an output of less than 150,000 tonnes in 1979. Up to the Second World War virtually all the fireclay was extracted by underground mining; many collieries, being steam powered, required considerable quantities of fireclay bricks for their own boiler linings. The last two fireclay mines, working the Tilley and Bottom Three-quarter seams near Bishop Auckland, closed in 1975 and fireclay production is now almost wholly from NCB opencast coals mines, with minor quantities from licensed sites. Most is used in the manufacture of buff facing bricks, although substantial quantities are also used in the production of ladle bricks and general purpose firebricks, with alumina contents in the range 30 to 36 per cent. Only one manufacturer (at Newfields near Bishop Auckland), producing fireclays and mudstones associated with the Bottom Tilley Coal for facing bricks, has a captive source of supply.

The Coal Measures crop out from Amble in the north to the vicinity of Bishop Auckland in the south and dip generally eastwards (Fig 9). The Lower and Middle Coal Measures are some 725 m thick and opencast coal mining is largely confined to the 275 m or so of strata between the Victoria and High Main coals (Fig 10). Coal seam nomenclature is confused by the fact that various names have been given to the same seam in different parts of the coalfield, and also by the same name being given to more than one seam. Standard county names have now been agreed, although local seam names still tend to be used.

Several fireclays mainly within the upper part of the Lower Coal Measures, are, or have been, of commercial value, although those associated with the Tilley and the Top Busty coals have been the most important. Those associated with the Tilley coals, particularly the Middle Tilley and its equivalent Bottom Widdrington Yard of Northumberland, are used mainly for refractory purposes and generally have uncalcined alumina contents in the range 28-31 per cent (*see* Table 6). The Top Busty fireclay, including its equivalent in Northumberland, the Widdrington Five-Quarter, is used in buff brick manufacture as is the Top Widdrington Yard (Tilley) and Bottom Widdrington Main (Three-quarter). Small quantities of fireclay associated with the Harvey Marine Coal have also been produced.

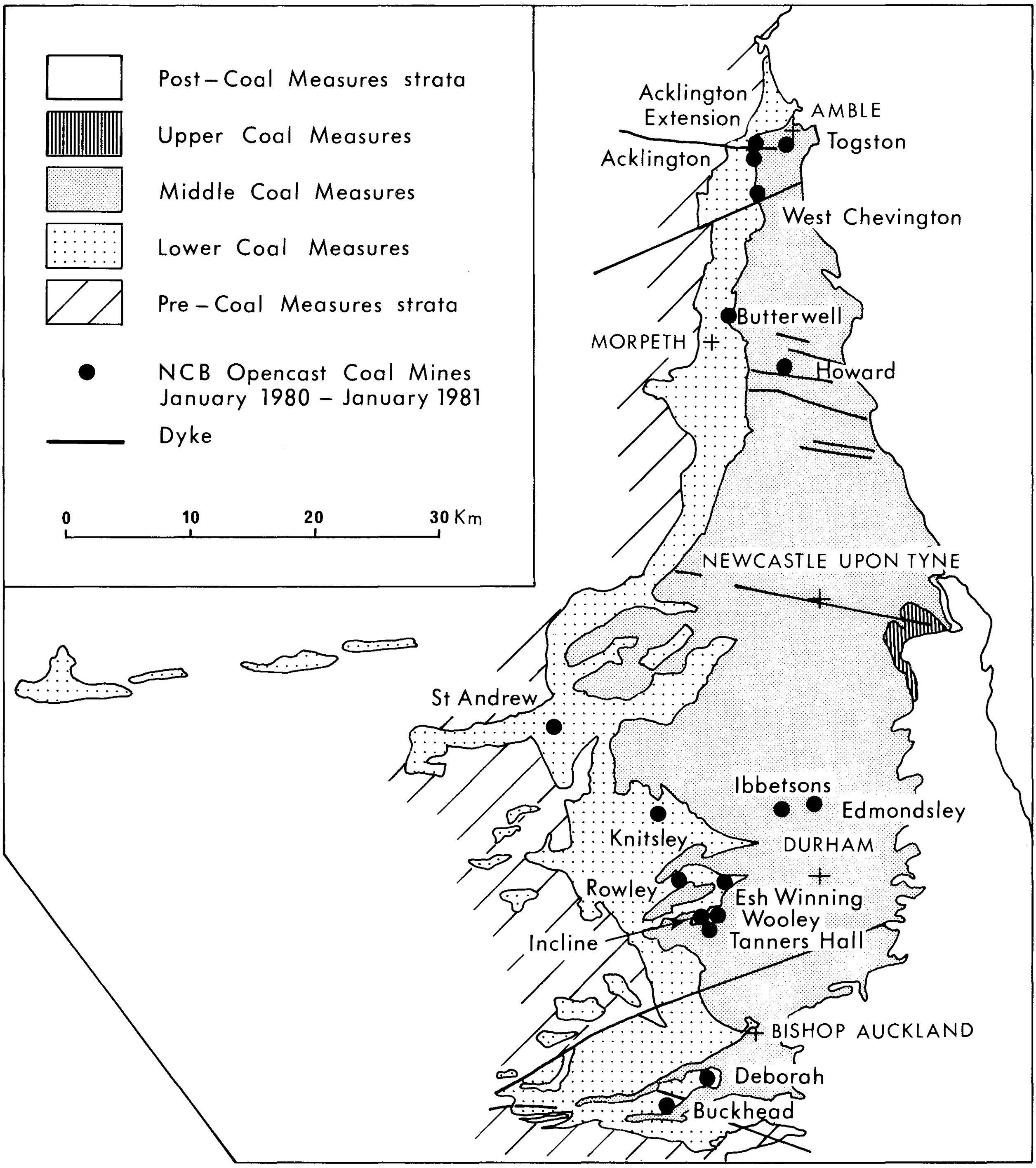

Fig 9 Location of opencast coal mines in the Northumberland and Durham Coalfield.

The fireclays, which occur as seatclays to coal seams, are rarely more than 1 m thick and are usually in the range 0.3 m to 0.6 m and it is quite common for fireclays of 0.3 m to be worked. They have a wide range in composition. For example, analyses by the NCB of a large number of fireclays associated with the Tilley coals gave a range of calcined alumina contents between 16 and 39 per cent, but with 75 per cent of the total falling between 25 and 34 per cent. Most of the more aluminous fireclays occur in the Lower Coal Measures.

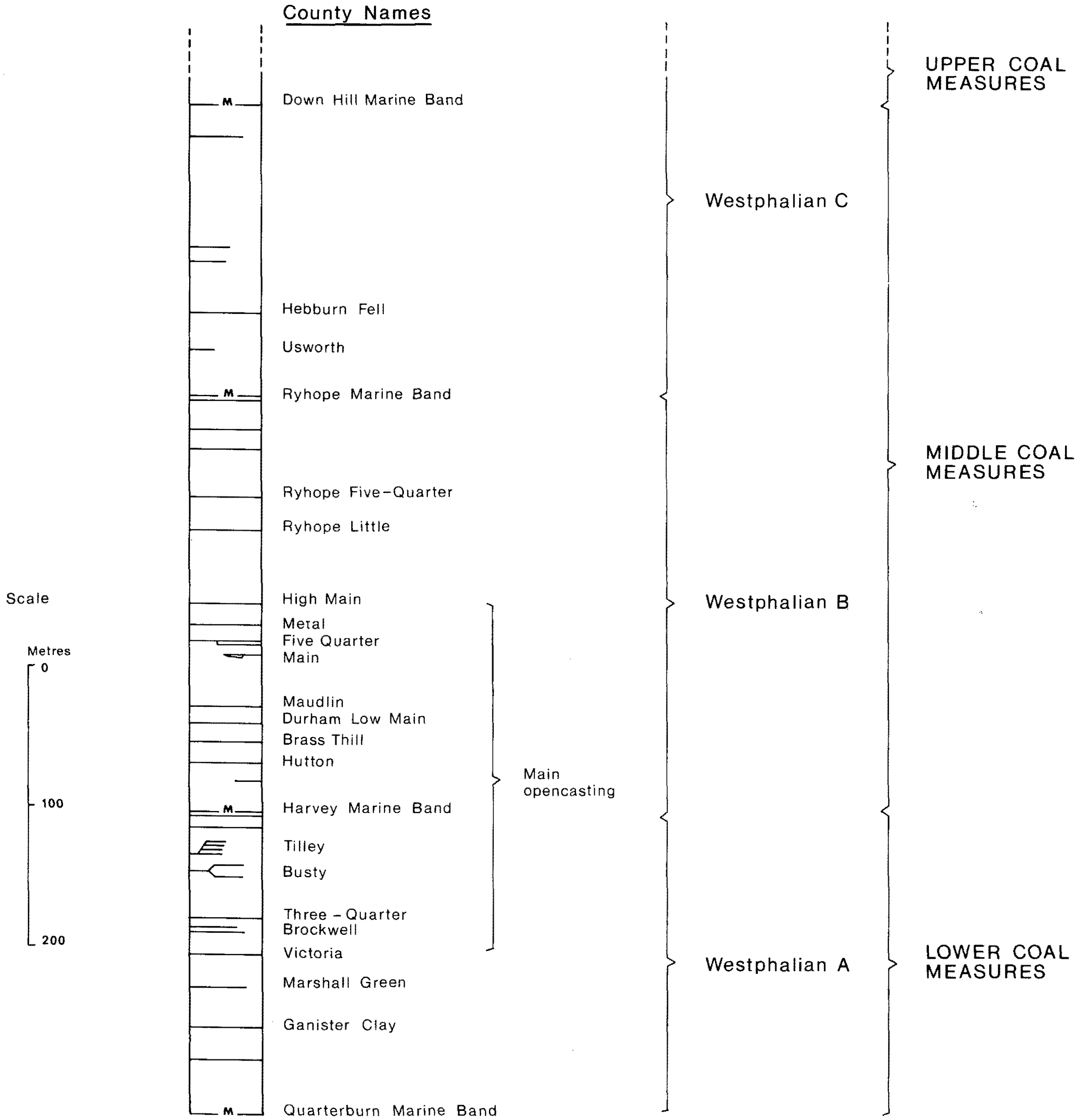

Fig 10 Coal Measures succession in the Northumberland and Durham Coalfield.

Forecast opencast coal production is approximately 2 million tonnes a year from Northumberland and 1 million tonnes from Durham, where the sites are much smaller. Opencast coal reserves for the coalfield have been estimated at 195 million tonnes by the Opencast Executive, adequate to support the opencast coal industry well into the next century. As opencast mining will tend to move eastward, thus working seams higher in the geological succession, the availability of fireclays from the Lower Coal Measures, on which present production is based, may diminish in the future. However, the indications are that a range of seatclays wider than

Table 6 Typical analyses of fireclays from the Northumberland and Durham Coalfield

	Wt %				
	1	*2*	*3*	*4*	*5*
SiO_2	52.0	53.18	51.5	63.6	54.2
Al_2O_3	30.4	29.54	31.4	23.3	29.6
Fe_2O_3	1.74	1.12	1.69	2.16	1.93
CaO	0.17	0.17	0.21	0.14	0.19
MgO	0.73	0.71	0.71	0.38	0.57
Na_2O	0.05	0.02	0.06	0.06	0.05
K_2O	1.99	1.96	1.46	0.79	1.13
TiO_2	1.05	1.03	1.34	1.23	1.31
Loss on ignition	11.2	11.59	11.4	8.39	10.8

Source: 1. Middle Tilley. Rowley NCB opencast coal site. Steetley Brick Ltd.
2 Middle Tilley. Esh Winning NCB opencast coal site. British Steel Corporation.
3 Bottom Widdrington Yard (Tilley). Butterwell NCB opencast coal site. The Burn Fireclay Co Ltd.
4 Top Widdrington Yard (Tilley). Sisters NCB opencast coal site. Steetley Brick Ltd.
5 Widdrington Five-Quarter (Top Busty). Butterwell NCB opencast coal site. Steetly Brick Ltd.

those currently utilised are of commercial quality and fireclay supplies from this coalfield therefore appear reasonably assured in the longer term.

Opencast coal mining, now confined to the Lower and Middle Coal Measures, is to be extended to the Scremerston Coal Group (Lower Carboniferous) in Northumberland. Little information is available on the quality of the associated seatclays, but trials in the early 1960s suggested that some of the clays are calcareous and therefore unsuitable for refractory purposes.

East Pennine Coalfield

Fireclay production in the Yorkshire-Derbyshire-Nottinghamshire Coalfield has historically been confined mainly to Yorkshire along a belt of Lower Coal Measures extending from Sheffield northwards through the Penistone-Denby Dale area to Halifax and Leeds. Production has also been fairly extensive in the Chesterfield area of north Derbyshire. Production was formerly much more important than it is at present; in 1950, output from the Halifax-Leeds area alone was 290,000 tonnes, at least an order of magnitude greater than today. The fireclays were used mainly in the production of refractory goods, salt-glazed pipes, sanitary ware and pottery. The Denby Dale-Penistone district is still a major centre for vitrified clay pipe production although the raw materials used are primarily Lower Coal Measures mudstones and not fireclays. The higher alumina, more refractory fireclays occur near the base of the Lower Coal Measures, whilst higher in the succession the fireclays have generally low alumina contents (23 to 26 per cent) and are of limited value for refractory purposes. The coal seams towards the base of the Lower Coal Measures tend to be thin and of poor quality, and production of fireclay has mainly been by underground mining, except for the Better Bed Coal and fireclay which have been extensively worked by opencast methods. The East Pennine Coalfield is a major source of opencast coal, but mining is confined to the upper part of the Lower Coal Measures and the Middle Coal Measures. Opencast coal mining has therefore supported only a relatively limited production of fireclays in recent years.

Historically, perhaps the most important fireclay in the East Pennine Coalfield has been the Stannington Pot Clay, the seatclay of the thin (<0.1 m) Pot Clay Coal, which occurs immediately below the Subcrenatum Marine Band which marks the base of the Lower Coal Measures: it is, therefore, of Namurian age (*see* Fig 11). It was originally used in making crucible pots, but its refractoriness, thermal shock resistance and ability to bloat at steelmaking temperatures, made it suitable for the manufacture of casting pit refractories. Production of the Stannington Pot Clay was largely based on drift mining in the Loxley Valley area to the north-west of Sheffield, but only one mine (the Storrs Bridge Mine) remains and this has a limited life. Recent mine closures have been caused by high mining costs and exhaustion of reserves. Until the mid-1970s about 80 per cent of United Kingdom casting pit refractory production was based on the Stannington Pot Clay, the industry being concentrated in the Loxley Valley area. Production is now largely based on fireclays from outside the area, mainly from the South Derbyshire Coalfield (P31 and P33 fireclays), but also aluminous fireclays from Scotland and Devon ball clay.

The Stannington Pot Clay ranges from 0.3 m to 2.7 m in thickness, but averages 1.5 m to 1.7 m, the highest quality material having a calcined alumina content of 37 to 38 per cent, although the alumina content generally decreases from top to bottom of the seam (38 to 30 per cent Al_2O_3 calcined). Typical analyses are included in Table 7.

Table 7 Typical analyses of fireclays from the Coal Measures, Yorkshire

	Wt %					
	1	*2*	*3*	*4*	*5*	*6*
SiO_2	47–51	49.49	47.08	n.a.	69.6	59.5
Al_2O_3	30.33	29.85	31.94	34.61	20.4	30.6
Fe_2O_3	3.5	4.22	2.72	4.56	1.87	2.9
CaO	n.a.	0.38	n.a.	n.a.	0.18	0.26
MgO	0.8	1.10	n.a.	n.a.	0.12	1.18
Na_2O	0.15	0.19	0.14	0.09	0.07	0.34
K_2O	1.6	1.54	0.22	0.91	0.44	3.88
TiO_2	0.9	1.16	1.99	n.a.	n.a.	1.30
C	0.5–1.5	1.32	n.a.	n.a.	n.a.	n.a.
Loss on ignition	11.13	11.72	18.53	11.28	7.26	11.3

n.a. not available

Source: 1 Pot Clay. Loxley. Euroclay, 1974, March/April. p. 10.
2 Pot Clay. Storrs Bridge Mine, Loxley. Thomas Marshall & Co (Loxley) Ltd.
3 36 Yard (Upper half). Park Nook Mine, Halifax. Samuel Wilkinson & Sons Ltd.
4 36 Yard (Calcined). Mean. Park Nook Mine, Halifax. Samuel Wilkinson & Sons Ltd.
5 Halifax Hard Bed. Halifax. Parkinson and Spencer Ltd.
6 Swinton Pottery (Calcined). Normanton. Analytical Chemistry Unit. Institute of Geological Sciences.

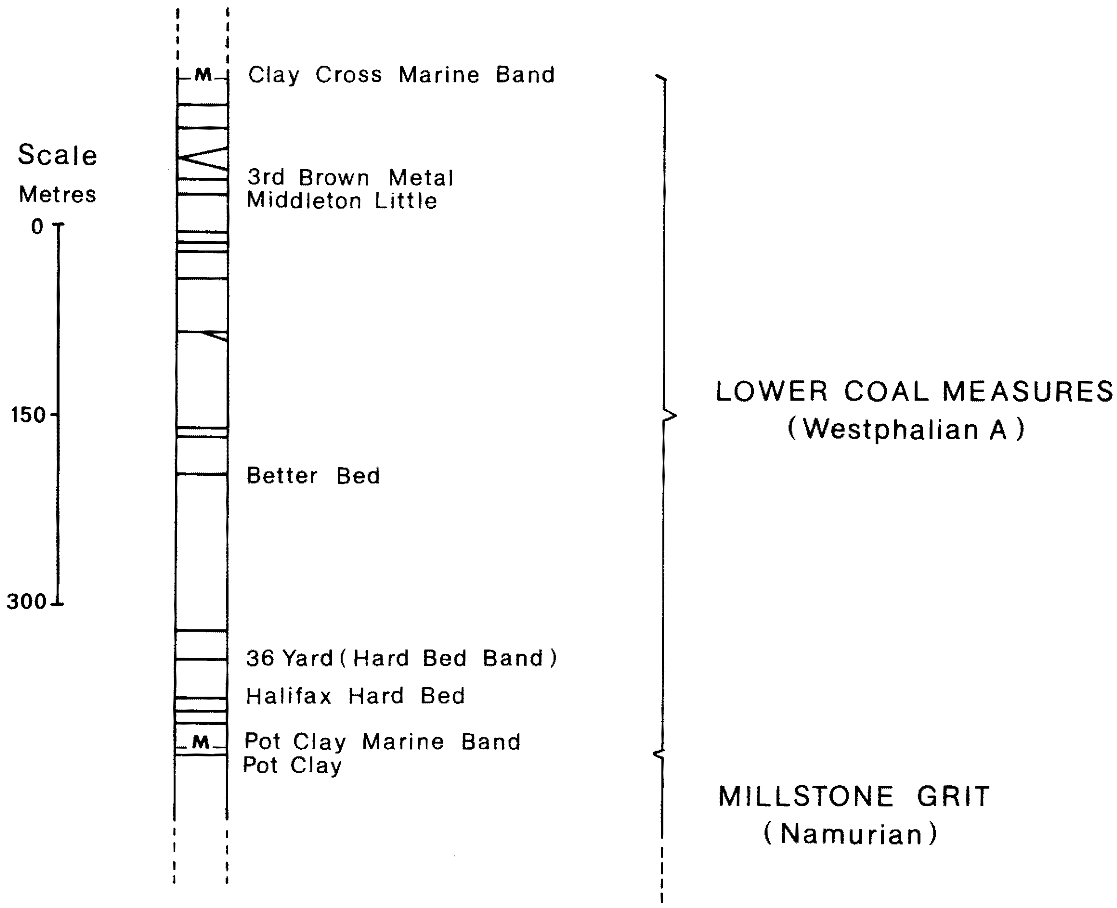

Fig 11 Stratigraphical distribution of fireclays within the Lower Coal Measures of the Yorkshire Coalfield.

Steep terrain has prevented opencast mining, except near the outcrop of the Pot Clay on the moors to the west of the Loxley Valley, where there are several small workings. The fireclay, which is up to 2 m thick, may contain up to 10 per cent carbon in its upper half, which severely limits the amounts that can be used without pre-calcination. However, parts of the outcrop have low carbon contents, for example, where worked opencast at Ughill it contained less than 1.5 per cent.

Refractory fireclays towards the base of the Lower Coal Measures have been extensively worked in the Halifax area and a small production, mainly from drift mines, continues for the manufacture of firebricks and glasshouse pots. The most important are associated with the Halifax Hard Bed and 36 Yard coals. North of the River Calder the 36 Yard Coal occurs as a single seam, but south of the Calder the Hard Bed Band Coal appears below and separated from it by a refractory fireclay. As the 36 Yard Coal disappears within a short distance, leaving the Hard Bed Band Coal, they are considered to be equivalent on a regional scale. On each side of the River Calder the fireclay beneath the 36 Yard Coal is highly refractory and is extracted by drift mining near Halifax. The seam, which is 1.5 m thick, consists of an upper, darker fireclay grading 36 to 38 per cent Al_2O_3 (calcined) and a lower medium-grey fireclay grading 32 to 34 per cent Al_2O_3 (calcined). The fireclay has also a low alkali content (<1.0 per cent Na_2O + K_2O) and is therefore highly refractory. Typical analyses are shown in Table 7. The fireclay associated with the underlying Hard Bed Band Coal was, until comparatively recently, mined at Elland (Ashgrove No. 1 mine) for the manufacture of salt-glazed pipes. The fireclay of the Halifax Hard Bed Coal is a siliceous clay with a low alumina content (20 to 22 per cent, uncalcined), but is unusual in having a low iron and alkali content (Table 7). It is extracted in the Halifax-Oxenholme area, by both small-scale opencast and underground mining, for the manufacture of glasshouse pots—refractory pots used for melting special glasses—and certain glass tank furnace blocks. A low iron content is essential to prevent contamination of the glass, and a siliceous fireclay is utilised to prevent excessive firing shrinkage.

Higher up in the Lower Coal Measures the fireclays to the Better Bed and 3rd Brown Metal coals were worked to the west and south-west of Leeds, particularly near Tong, where opencast mining was of considerable importance, since the Better Bed Coal is of good quality. The fireclay to the Better Bed Coal, which is some 0.6 to 0.7 m thick, is comparatively low in alumina (21 to 30 per cent uncalcined) but also has low alkalis (0.8 to 1.6 per cent Na_2O + K_2O). Among other uses, it was used in making coke oven bricks. The vitreous 3rd Brown Metal fireclay was used in the manufacture of sanitary fireclayware (urinals and sinks), vitreous floor tiles and sewer pipes. These fireclays, typical analyses of which are given in Table 8, are no longer worked. The fireclay under the Swinton Pottery Coal (Middle Coal Measures), formerly used in pottery manufacture, has also been worked for vitrified clay pipe production: the vitreous character of the clay being indicated by the high alkalis content (Table 7), effecting an appreciable mica content.

In recent years fireclay production from NCB opencast mines has been confined to the Oxbow-Charcoal sites near Temple Newsham, south-east of Leeds, where limited quantities of 3rd Brown Metal fireclay have been produced for use as taphole clays and, more importantly, the Middleton Little for buff brick manufacture.

Elsewhere, fireclay production has been on a limited scale. The Tupton and Tupton Threequarters in the Lower Coal Measures were until recently worked in the Chesterfield area for stoneware manufacture and there are proposals to work the Deep Soft and Deep Hard fireclays near Denby, also for stoneware pottery manufacture. The Tupton and Deep Hard fireclays were formerly used also in ladle brick production.

The vitrified clay drainageware industry in the Penistone-Denby Dale area is predominantly based on a blended feed of locally won Lower Coal Measures mudstones, although some fireclays are imported into the area. Several beds are worked to give the blend the desired vitrification

Table 8 Typical analysis of some fireclays from the East Pennine Coalfield

	Wt %						
	1	*2*	*3*	*4*	*5*	*6*	*7*
SiO_2	70.2	52.85	57.88	65.27	56.9	60.7	70.9
Al_2O_3	17.8	30.85	21.31	21.58	24.2	29.1	22.22
Fe_2O_3	1.33	1.82	1.22	1.12	3.5	2.32	1.58
CaO	0.16	1.52	1.03	0.25	0.15	0.13	0.16
MgO	0.71	n.a.	n.a.	n.a.	1.2	1.33	0.86
Na_2O	0.24	0.18	1.06	0.17	0.26	0.30	0.18
K_2O	2.50	1.18	3.73	0.75	3.4	4.8	2.94
TiO_2	1.05	1.19	0.41	0.60	1.0	0.93	1.11
Loss on ignition	5.83	11.48	12.21	8.86	9.4	0.27	0.07

n.a. not available

Source: 1 Middleton Little. Oxbow/Charcoal NCB Site. George Armitage and Sons Ltd.
2 Better Bed. Colne Bridge, Mirfield. Leeds Fireclay Co Ltd.
3 3rd Brown Metal. Howden Clough, south-west of Leeds. Leeds Fireclay Co Ltd.
4 Better Bed. Tong, west of Leeds. Leeds Fireclay Co Ltd.
5 Tupton. Chesterfield. Marshall Refractories Ltd
6 Tupton Threequarters. Chesterfield. Pearson & Co (Chesterfield) Ltd
7 Tupton. Chesterfield. Pearson & Co (Chesterfield) Ltd

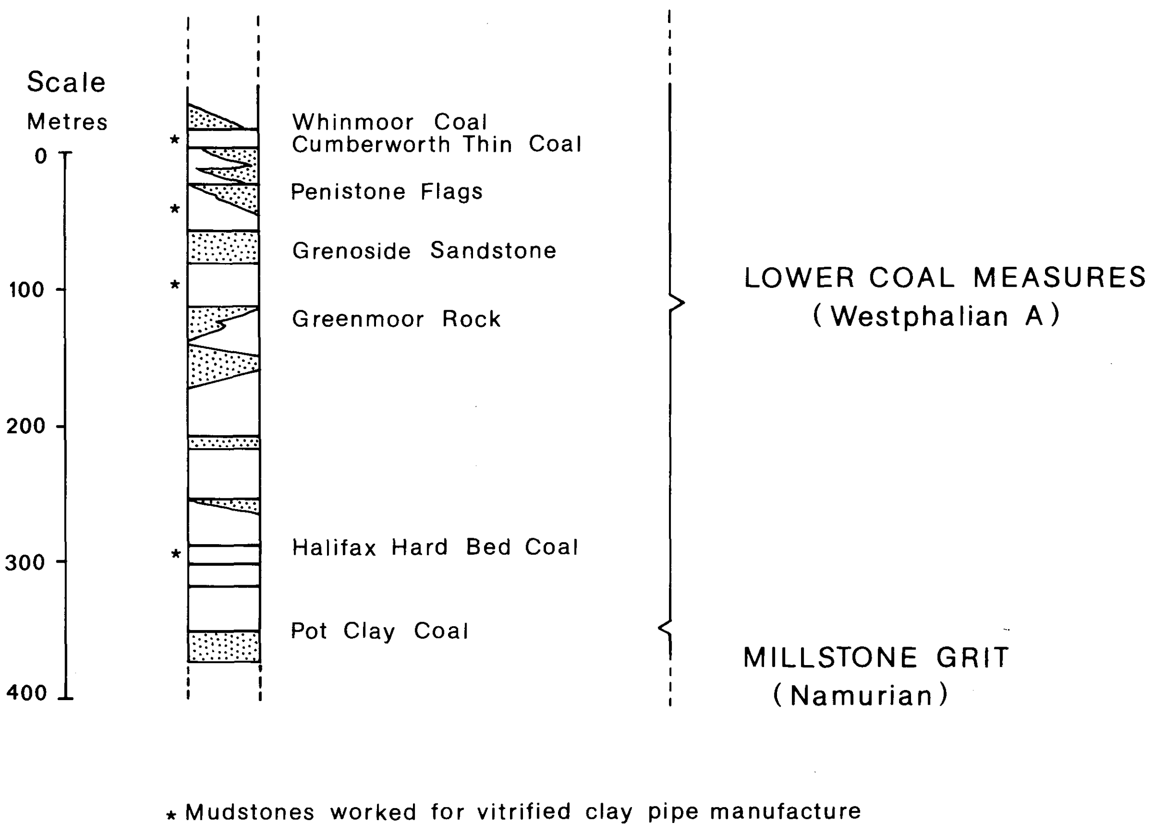

Fig 12 Stratigraphical distribution of mudstones and fireclays used for vitrified clay pipe manufacture in the Penistone district. (Based on D. Ashby. *In*: Guide book to Midlands of England Field Excursion. Sixth International Clay Conference, 1978).

characteristics, the major limitation on the raw materials used being carbon and sulphur levels. Output is not related to opencast coal mines, although minor quantities of coal are produced as an ancillary mineral. The two main beds worked are associated with the Halifax Hard Bed, Cumberworth Thin and Whinmoor coals (Fig 12). A pale to dark grey mudstone, known locally as 'Blue Clay', some 3 m to 5 m thick, occurs beneath the arenaceous seatearth (ganister) of the Halifax Hard Bed Coal in the Hazelhead area. Up to 20 m of black carbonaceous shales are removed as overburden to work the mudstone, which is valued because of its low carbon and sulphur (pyrite) contents, resulting from seatearth-type leaching action associated with the overlying ganister. The dominantly illitic mudstones and silty mudstones between the Cumberworth Thin and Whinmoor coals and the kaolinitic seatclay to the Cumberworth Thin Coal are also worked. Mudstones below the Penistone Flags and between the Grenoside Sandstone and Greenmoor Rock are also included in the blend. Resources of clays suitable for the manufacture of vitrified clay pipes are very large and potential also exists for the use of fireclays and mudstones from opencast coal mines in the Yorkshire Coalfield where these are of suitable quality and within economic distance of existing manufacturers.

Lancashire Coalfield

The once extensive fireclay mining industry in Lancashire is now only a fraction of its former size. Production in 1953 was some 153,000 tonnes and about 90 per cent of total output was won by underground mining. Current production is not available but is probably less than 30,000 tonnes and there are no underground mines. The fireclays of former economic interest were mainly confined to the lower half of the Lower Coal Measures, between the Lower Foot and Pasture Mine coals, although several were also mined from the top of the Millstone Grit, whereas the main coal-bearing sequence occurs in the upper part of the Lower Coal Measures and the lower half of the Middle Coal Measures.

A low-carbon mudstone beneath the ganister of the Lower Mountain Mine (or Ganister Coal) is worked near Rochdale and used in the blended feed for vitrified clay pipe production, together with the highly vitreous mudstones ('Accrington Mudstone') beneath the Old Lawrence Rock also within the Lower Coal Measures. Buff-burning fireclays were also produced from a brick clay quarry in the Middle Coal Measures near St. Helens. No fireclays are currently produced from NCB opencast coal mines in the coalfield, although there is a large market for buff-burning fireclays in Lancashire if clays of suitable quality are identified in future opencast coal sites.

South Derbyshire and Leicestershire Coalfield

The South Derbyshire Coalfield, which is bounded in the east by the Boothorpe Fault and separated from the Leicestershire Coalfield by the Ashby Anticline, is currently by far the most important source of fireclay in the United Kingdom. The fireclays of present commercial value are almost entirely confined to the Pottery Clays Formation in the Middle and Upper Coal Measures, exposed in the relatively small Moira-Swadlincote area in a narrow, faulted, irregular syncline. The formation is some 100 m thick and contains numerous thin, relatively poor quality coals, the concentration of the seatclays being a factor of considerable economic importance. To aid correlation, each coal seam and associated seatclay has been numbered in descending order with the prefix 'P', the base of the Pottery Clays Formation being taken at the base of the seatclay of the P40 coal (*see* Fig 13). Some of the fireclays have been further subdivided by the clay operators on the basis of their chemistry and carbon content, i.e. P31A, P36D and P36L (D and L indicating dark and light, a reflection of carbon content) and these may be extracted separately. The fireclays have been produced on a large scale, both for refractory and non-refractory applications, since the mid-19th century, the formation name being derived from the former use of the clays in pottery manufacture; relatively small quantities of fireclay are still used in the manufacture of stoneware pottery. The Derby (P31) and Deep (P33) fireclays have long been valued as refractory clays, their high alumina contents (Table 9) being unusual for fireclays of Upper Westphalian B age, since elsewhere higher alumina fireclays are generaly Lower Westphalian A or Namurian. The district was a major centre of salt-glazed pipe production both prior to and after the Second World War, output being based primarily on the aluminous Derby (P31) fireclay and the underlying and more siliceous Derby Bottle Clay. With the demise of salt glazing the area has become one of the two major centres for vitrified clay pipe production in the United Kingdom, for which most of the locally won fireclays are used.

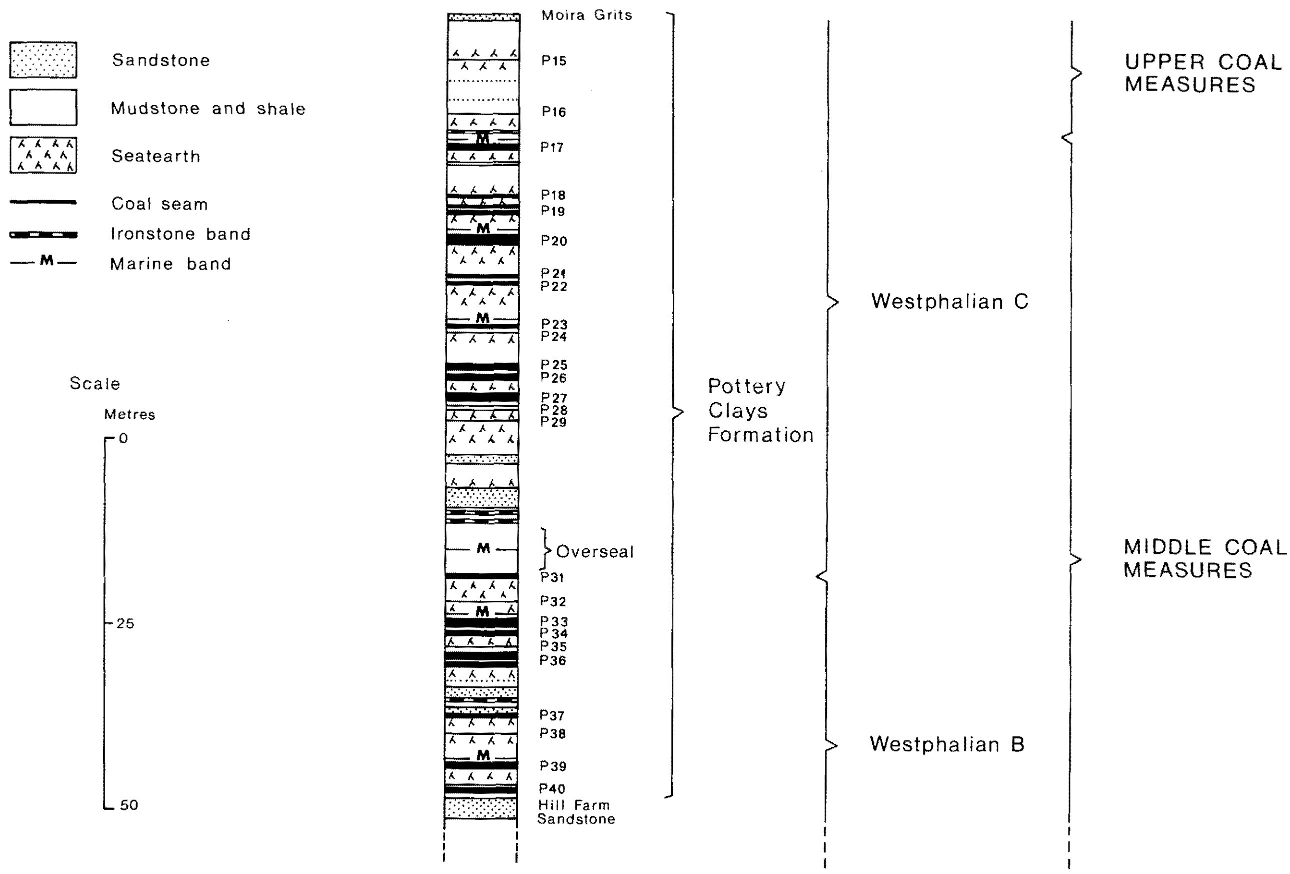

Fig 13 Stratigraphical distribution of fireclays in the Pottery Clays Formation of the South Derbyshire Coalfield. (Based on B. C. Worssam. *Bull. geol. Surv. Gt Br.*, 1977, No. 63, p. 3).

The orderly and efficient extraction of the coal and fireclay resources of the area was prevented, until the early 1970s, by a multiplicity of mineral rights ownerships and planning permissions, which arose during the long history of fireclay working. Large areas were sterilised by the boundaries between adjacent sites and stockpiles. Rationalisation within the industry and joint workings between the NCB and mineral rights owners has now allowed large scale opencast mining to be undertaken, with co-ordinated plans for both coal and fireclay extraction. This has resulted also in much improved land reclamation after mining.

Table 9 Typical chemical analyses of fireclays from the Donington Extension opencast coal mine, South Derbyshire Coalfield

	Wt %							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
SiO_2	66.88	66.37	69.66	70.51	45.19	56.20	60.09	61.99
Al_2O_3	16.73	19.74	18.48	17.42	33.47	27.51	24.34	21.72
Fe_2O_3	4.14	1.64	1.29	1.62	1.92	2.02	2.84	2.38
CaO	0.14	0.06	0.10	0.13	0.30	0.20	0.22	0.25
MgO	0.49	0.66	0.40	0.48	0.66	0.55	0.60	0.78
Na_2O	0.06	0.30	0.16	0.10	0.20	0.12	0.22	0.14
K_2O	1.49	2.36	1.08	1.57	1.69	1.85	2.02	2.20
TiO_2	1.02	1.09	1.56	1.17	1.30	1.41	1.31	1.28
Loss on ignition	8.00	7.82	7.37	7.10	15.06	9.48	8.81	9.11
	9	*10*	*11*	*12*	*13*	*14*	*15*	*16*
SiO_2	61.73	45.50	58.36	45.79	57.53	56.88	49.80	64.00
Al_2O_3	23.29	32.77	22.15	33.52	24.79	25.18	28.76	20.15
Fe_2O_3	1.40	1.95	3.76	2.13	3.73	1.68	2.11	2.89
CaO	0.20	0.28	0.21	0.29	0.14	0.18	0.20	0.11
MgO	0.67	0.61	0.79	0.83	0.84	0.85	0.93	0.75
Na_2O	0.20	0.10	0.12	0.13	0.35	0.18	0.21	0.24
K_2O	2.18	1.93	2.19	2.10	1.29	2.94	2.54	3.09
TiO_2	1.15	1.10	1.19	1.40	1.20	1.16	1.16	1.15
Loss on ignition	9.36	15.11	10.77	12.94	9.54	10.42	14.14	7.52

Source: Donington Extension Minerals Consortium.

1 P20; 2 P22; 3 P24; 4 P26; 5 P31; 6 P31A; 7 P31B; 8 P31B1; 9 P31B2; 10 P31C; 11 P31D; 12 P33; 13 P34L; 14 P35; 15 P36D; 16 P39.

These operations, in which fireclay production greatly exceeds coal output, are, therefore, unlike opencast coal mines elsewhere in the United Kingdom. However, despite a large local consumption of fireclay, principally in the production of vitrified clay pipes, fireclay extraction is still in excess of demand and large stockpiles are being built up. Fireclay stockpiles in the South Derbyshire Coalfield amount to some 5 million tonnes and are currently being increased by approximately 0.5 million tonnes a year. The main opencast coal/fireclay mine in the South Derbyshire Coalfield is the Donington Extension site, which came into production in 1979 and is currently producing 0.5 million tonnes of coal and 1 million tonnes of fireclay a year. Coaling is expected to be completed in late 1984. Originally, the site was expected to yield some 12 million tonnes of fireclay, but, because of falling demand, this is now expected to be some 8 million tonnes, a significant proportion of which will be stocked below restoration levels and may never be used. The rights to the fireclay are owned by four companies forming the Donington Extension Minerals Consortium, which came to an agreement with both the NCB Opencast Executive and their contractors which allowed for a co-ordinated plan for the extraction of both coal and fireclay. The fireclays are extracted under the supervision of the Consortium and stockpiled for eventual sale back to the mineral rights owners in proportion to their original ownership.

Thirteen seams between the P20 and P39 are worked and an aggregate thickness of 22 m extracted. The fireclays are worked to 28 different specifications necessitating the careful extraction of individual parts of seams. For example, the P31 fireclay, with a thickness of some 5.2 m, is recovered in 8 separate lifts to give 7 separate grades for individual stocking. Continuous monitoring of the fireclays is carried out by the Consortium and if a particular seam does not conform to a set specification it is either downgraded or removed as overburden waste. The fireclays vary significantly in quality (Table 9), the main refractory (aluminous) clays being P31 and P33, although P34D and P36L may also have uncalcined alumina contents over 30 per cent. These clays are used, for example, in the blend for bloating ladle brick production. The fireclays have comparatively high alkali contents and sinter more readily than might be expected for clays with relatively high alumina contents. In addition to the manufacture of bloating ladle bricks they are now the main source of fireclay used in the production of casting pit refractories. Nine fireclays between P28 and P39 are used in the blend for vitrified clay pipe manufacture. Large scale blending of more aluminous fireclays, with increasing proportions of siliceous fireclays, has considerably extended the reserves and allowed a more intense and efficient utilisation of the total clay resource in the area. Some of the fireclays are also used in the manufacture of buff facing bricks and other building products and in stoneware pottery bodies. Further sites for working coal and fireclay occur within the Pottery Clays Formation and it seems likely that the area will remain the most important source of fireclay in the United Kingdom well into the next century.

A licensed opencast coal site at Willesley Wood on the eastern margin of the coalfield also exploits the Pottery Clays Formation and is an important source of fireclays with signficiant quantities stockpiled. Typical analyses are shown in Table 10 indicating that, assuming the seam correlation to be correct, lateral variation in quality between there and Donington is considerable in at least one seam (P31).

Within the Leicestershire Coalfield, east of the Ashby Anticline, small quantities of siliceous stoneware fireclays were produced at Lountwood near Ashby de la Zouch. The seams worked were the Middle Lount and Nether Lount in the Lower Coal Measures, the former being regarded as the better quality for stoneware.

Table 10 Typical chemical analyses of fireclays, Willesley Wood opencast coal mine, South Derbyshire Coalfield

	Wt %					
	1	*2*	*3*	*4*	*5*	*6*
SiO_2	56.1	74.4	61.0	63.1	61.3	66.2
Al_2O_3	36.5	20.0	30.9	30.1	32.6	24.4
Fe_2O_3	2.26	2.05	3.58	2.18	1.78	4.94
CaO	0.06	0.03	0.06	0.04	0.08	0.17
MgO	0.48	0.01	0.75	0.77	0.75	0.77
Na_2O	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
K_2O	1.84	1.30	2.34	2.48	2.21	1.77
TiO_2	1.48	1.09	1.39	1.31	1.34	1.30
Loss on ignition	12.73	7.11	12.25	11.60	12.86	11.38

n.a. not available

Source: Castle Clay Sales Ltd
1 P27/28, 0-0.6 m;
2 P27/28, 0.6-1.2 m;
3 P25/26, 0-1 m;
4 P 25/26, 1 m-1.5 m;
5 P29/30, 0-1 m;
6 P31, 0-6 m.

South Staffordshire Coalfield

The South Staffordshire Coalfield extends from near Rugeley in the north to the Lickey Hills in the south and consists structurally of a denuded anticline bounded on the east and west by faults. Both the Lower and Middle Coal Measures thin southward from the Cannock area, with some of the coals coalescing to give thicker seams in the Dudley area; the Thick Coal is over 10 m thick in places. Farther south the coals, particularly in the lower part, become thinner and laterally impersistent. The famous Stourbridge fireclays were won from the southern part of the coalfield around Stourbridge and Halesowen, where the sequence consists mainly of fireclays. The fireclays were exploited in the 16th century for making pots for melting glass, but the area became prominent only in the 19th century when Stourbridge firebricks, widely used in gas retorts and coke ovens, gained a worldwide reputation.

The Stourbridge firebrick industry was based on several fireclays, mainly in the upper part of the Lower Coal Measures, exploited from deep shafts. The Old Mine fireclay below the Stinking Coal was the first to be mined, but as reserves became exhausted the various underlying New Mine clays, including those below the New Mine and Fireclay Coals, were worked. Correlation of these clays is difficult, but the lower New Mine fire clays were probably equivalent to those associated with the Fireclay and Bottom coals. The Stourbridge mines are now defunct and most of the area has been built over. Fireclay extraction in the South Staffordshire Coalfield is now confined to its northern part although large stocks of fireclay from a relatively recent opencast coal mine remain at Gornal Wood near Dudley: these fireclays, associated with the New Mine and Bottom coals, have calcined alumina contents in the range 27 to 36 per cent, and were intended for local use in the manufacture of coke oven refractories. Consumption of these stocks has, however, been greatly reduced owing to falling demand and the increasing requirement for material with higher alumina content.

In the northern (Cannock) part of the coalfield, fireclays have been worked near Brownhills and at Landywood, south of Cannock. At Brownhills, the fireclays associated with the Yard, Bass, Cinder and Shallow coals in the upper part of the Lower Coal Measures have been extracted in the course of opencast coal mining and stocked for future sale.

Table 11 Typical chemical analyses of some fireclays from the South Staffordshire Coalfield

	Wt %						
	1	*2*	*3*	*4*	*5*	*6*	*7*
SiO_2	54.2	70.8	76.3	52.7	65.3	61.8	59.4
Al_2O_2	29.3	18.4	14.6	30.1	21.4	24.6	25.50
Fe_2O_3	2.10	1.1	0.92	1.75	1.53	1.11	1.70
CaO	0.27	trace	0.18	0.24	0.16	0.18	0.24
MgO	1.06	0.6	0.28	0.71	0.62	0.4	0.70
Na_2O	0.09	0.1	< 0.05	0.16	0.2	0.02	0.14
K_2O	2.94	2.2	1.26	2.46	2.59	1.39	1.56
TiO_2	1.25	1.2	1.01	1.23	1.28	1.69	1.39
Loss on ignition	8.53	5.6	4.94	10.2	6.65	8.2	8.89

Source: 1 Cinder—upper part (uncalcined). Birch Coppice site, Brownhills. Potclays Ltd.
2 Shallow (uncalcined). Birch Coppice site, Brownhills. Potclays Ltd.
3 Charles A (uncalcined). Kingswood NCB opencast, Cannock. Whitfield Minerals Ltd.
4 Charles B (uncalcined). Kingswood NCB opencast, Cannock. Whitfield Minerals Ltd.
5 Charles E (uncalcined). Kingswood NCB opencast, Cannock. Whitfield Minerals Ltd.
6 Charles F (uncalcined). Kingswood NCB opencast, Cannock. Whitfield Minerals Ltd.
7 Charles E (uncalcined). Landywood site, Great Wyrley. Hawkins Tiles (Cannock) Ltd.

The fireclay beneath the Shallow Coal and the upper section of the Cinder fireclay have some properties akin to certain ball clays; they are used in pottery bodies, for craft and studio work and for several other applications such as the manufacture of buff bricks. The fireclays associated with the Charles coals in the Middle Coal Measures, which may consist of up to six leaves, are plastic, near-white firing and vitreous, and also have properties similar to those exhibited by some ball clays. As they also have very low carbon contents of less than 0.5 per cent, they have attracted a considerable amount of commercial interest.

X-ray diffraction examination of samples of the Shallow and Cinder fireclays from Brownhills and the Charles B fireclay from Great Wyrley showed that the main constituents were kaolinite, quartz and mica in variable proportions, together with small amounts of mixed-layer illite-smectite and vermiculite. Rational mineralogical analyses calculated from chemical analyses of the fireclays are shown in Table 12. Particle size analyses showed that only that Charles B fireclay, which contains some 69 per cent of particles finer than 2 μm equivalent spherical diameter, approaches higher grade commercial ball clays in grain size.

Table 12 Rational mineralogical analyses and particle size data on fireclays from the South Staffordshire Coalfield

	Charles B	*Shallow*	*Cinder*
Kaolinite	68.8	28.7	44.7
Mica	16.2	23.5	26.8
Quartz	8.5	43.4	19.2
% of original sample $>63\ \mu m$	0.4	11.6	3.2
$<63\ \mu m$ fraction % less than $10\ \mu m$	94	57	94
$2\ \mu m$	69	23	39
$1\ \mu m$	48	14	22

Source: Applied Mineralogy Unit, Institute of Geological Sciences.

The clay-water relationships of the fireclays were assessed using Atterberg Limits, which confirmed that the clays exhibit plastic behaviour similar to some ball clays. The vitrification characteristics of the fireclays were also evaluated using a temperature gradient kiln. The subsequent determination of the porosity, water absorption, volume shrinkage, bulk density and specific gravity of fired pieces allowed their firing behaviour to be monitored over the temperature range 900 to 1,250°C. The fireclays were found to vitrify over the same temperature range as ball clays and, for example, the Charles B fireclay produced a dense, non-porous body at 1,225°C, although the fired product had a greenish grey colour. Similarly, the Cinder and Shallow fireclays produced low porosity bodies (< 2 per cent) at 1,220° and 1,250°C, respectively, the former showing a slight tendency to bloat above this temperature. The higher quartz/kaolinite ratio of the Cinder fireclay produced markedly lower shrinkages in the upper part of the firing range. In terms of composition, plasticity and firing behaviour the fireclays were found to be comparable with some ball clays, although they did not exhibit the white to off-white fired colours normally associated with ball clays.

The fireclays associated with the Charles coals were formerly worked at Landywood near Great Wyrley and are present in substantial quantities in the NCB Kingswood opencast coal mine near Cannock. There are considerable resources in the Cannock area of fireclays which could potentially be used as alternatives to ball clays for certain applications.

Other Midland coalfields

The Warwickshire Coalfield is roughly oval in outline and extends southwards from Tamworth to Warwick. The productive Lower and Middle Coal Measures crop out in a narrow belt around the northern margin of the coalfield from Dosthill in the north-west to Bedworth in the east. No opencast coal mining activity is being carried out at present, but if plans for opencast mining in the area are realised it is likely that fireclays, which have been worked in the past for stoneware and firebrick manufacture, would again become available to the market.

In the North Staffordshire Coalfield fireclay production has been of only very minor importance in recent years, although the clays below the Bassey Mine and Peacock coals in the Upper Coal Measure were formerly used for tiles and in making saggars for the pottery industry. The fireclay associated with the Peacock Coal is used in making buff facing bricks. Opencast coal mining has recently started in the coalfield.

Coalbrookdale Coalfield

The Coalbrookdale Coalfield in Shropshire has a long history of mineral working, coal and ironstone having been the most important minerals produced largely as a result of the successful use by Abraham Darby in 1709 of coke as a reductant (replacing charcoal) in ironmaking. Their importance has declined markedly since the late 19th century, however, and ironstone production ceased entirely in 1950. Prior to the Second World War fireclay production was confined to relatively small scale underground mining. Following the introduction of opencast coal mining during the War production rose significantly, peak output of 391,000 tonnes being achieved in 1968. Despite a decline in output in recent years, the area is still one of the major centres of fireclay production in the United Kingdom, for use both locally for ladle brick production and elsewhere for use in the manufacture of refractories, fireclay sanitaryware, buff facing bricks and floor tiles. Formerly, large quantities were used in the manufacture of salt-glazed pipes, until vitrified clay pipes were introduced. Small quantities are used locally in the production of agricultural field drains. Total production of fireclay is about 150,000 tonnes a year.

Table 13 Stratigraphical distribution of fireclays within the Lower Coal Measures of the Coalbrookdale Coalfield

Coals	*Fireclays*
Big Flint	—
New Mine	Nine-feet Clay, Upper Clunch, New Mine Clay
Clunch (Viger)	Clunch, Lower Clunch, Viger Clay
Two Foot (Ganey coals in Broseley area with fireclays between)	Two Foot Clay, 'Linseed Earth', Ganey clays
Best	—
Randle	Fireclay locally below Randle Coal as in Caughley area
Clod	Fireclay below Clod Coal in Broseley area and north of the Severn

The Coal Measures of the Coalbrookdale Coalfield which total some 400 m in thickness, comprise a lower productive group (the Lower and Middle Coal Measures) unconformably overlain by the Upper Coal Measures. Economically important fireclays are confined to some 20 m or so of strata between the Little Flint and New Mine coals in the upper part of the Lower Coal Measures (Table 13). Most fireclays are associated with coal seams, but show considerable lateral variation in both thickness and quality, with 24 to 33 per cent Al_2O_3 (uncalcined) (Table 14).

Important fireclays are, in ascending stratigraphical order, the Clod, Randle, Ganey (Two Foot), Clunch and New Mine Clay (or Upper Clunch), the latter generally being regarded as the best quality. The Lower Coal Measures crop out widely in the west of the coalfield from Lawley to Little Wenlock and Ironbridge, north of the River Severn, and in the Broseley area in the south-western part of the coalfield, south of the River Severn. The fireclays, therefore, achieve their maximum development in the western part of the coalfield, but deteriorate in quality towards the east and become more siliceous.

The Hadley Formation, at the base of the Upper Coal Measures, is of Etruria Marl facies and unconformably oversteps the Lower Coal Measures in the Broseley area and at Caughley, where fireclays at the base of the Hadley Formation are worked and blended with other fireclays for the production of ladle and acid resistant bricks.

Table 14 Typical chemical analyses of fireclays from the Coalbrookdale Coalfield

	Wt %		
	1	*2*	*3*
SiO_2	58.2	49.1	56.05
Al_2O_3	24.7	31.7	36.80
Fe_2O_3	3.15	2.08	2.57
CaO	0.23	0.29	0.30
MgO	0.73	0.78	1.06
Na_2O	0.28	0.02	0.34
K_2O	4.15	1.73	1.58
TiO_2	1.08	1.39	1.76
Loss on ignition	7.10	12.09	—

Source: 1 Clod (uncalcined). Clares Lane NCB opencast site. Whitfield Minerals Ltd.
2 Clunch (uncalcined). Clares Lane NCB opencast site. Whitfield Minerals Ltd.
3 Clunch (calcined). Clares Lane NCB opencast site. Gibbons Refractories Ltd.

Fireclays have been extensively worked around Ketley, Little Wenlock and Horsehay, north of the Severn, and to a lesser extent in the Broseley area. The industry has contracted considerably during the last decade and of a number of long established private fireclay producing companies, only one is currently extracting clay, at Coalmoor, north of the River Severn, where reserves are limited, and at Caughley and Benthall in the south. However, large stocks of fireclay have been built up. The NCB have also pursued a policy of extracting and stocking fireclays with reasonably guaranteed sales, but the current Limekiln Lane site does not contain saleable fireclay and the NCB's Brandlee stocking ground, where the Clunch and Clod fireclays were stocked, is now approaching exhaustion. Coal reserves within the coalfield are now very limited and NCB mining is unlikely to continue for more than five years. Remaining reserves are mainly confined to the south of the River Severn, to the west of Broseley, where significant fireclay reserves also occur.

Wales

Fireclays have been produced from both the North and South Wales coalfields although in recent years production has been mainly from North Wales.

The Westphalian (Coal Measures) rocks of the North Wales Coalfield consist of a lower sequence of productive grey measures and an upper sequence of barren, largely red, measures which were laid down under oxidising conditions. Coals occur within the grey measures and several seatclays have been worked in the past as commercial fireclays. The most important fireclays occur within the Buckley Fireclay Group (Westphalian C) which lie between the grey and red measures and consist of grey, red and purple mudstones and fireclays, with no significant associated coals. The deposits have a limited areal extent, but have been extensively worked to the east and north-east of Buckley. The worked strata are some 12 m thick and consist of an upper section of mottled purplish to reddish grey fireclays ('Blue Clay') and a lower sequence of dark grey to black fireclays ('Black Clay'). The fireclays are overlain by thinly bedded and massive fine-grained sandstones. Historically, the fireclays of the Buckley Fireclay Group were used to produce refractories for the nearby Shotton steelworks, as well as for building bricks and acid resistant goods. Until recently large quantities of 'Black Clay' were used in the manufacture of ladle bricks, but this has now ceased with the closure of the steelplant. Most of the fireclay is now used in the production of a range of facing bricks, including buff and blue coloured, the latter being fired under reducing conditions.

Table 15 Typical chemical analyses of fireclays from North Wales

	Wt %	
	1	*2*
SiO_2	50	55
Al_2O_3	32.1	27.86
Fe_2O_3	3.34	5.44
CaO	0.60	0.03
MgO	0.52	0.01
Na_2O	0.20	0.15
K_2O	2.12	1.43
TiO_2	1	1
Loss on ignition	9.92	9.03

Source: 1. 'Black Clay'. Buckley Fireclay Group. Butterley Building Materials Ltd.
2 'Blue Clay'. Buckley Fireclay Group. Butterley Building Materials Ltd.

The Buckley Fireclay Group is obscured by drift deposits northwards and in the southern part of the North Wales Coalfield there appears to be no equivalent. Commercial fireclays occur at other horizons, however, particularly within the Lower Coal Measures. Fireclays occuring as partings within the Fireclay Coals and having a combined thickness of 2 m-2.5 m were mined until the mid-1970s near Ffrith for the production of casting pit refractories. The fireclay was of high quality with a calcined alumina content in the range 33 to 39 per cent. Fireclays associated with the Half-Yard, Unknown and Firedamp coals at the top of the Lower Coal Measures have been worked for several years from an alienated opencast coal site at Acrefair near Trevor, for use in the manufacture of buff bricks and for binding animal feedstuffs. A good quality, 32 to 33 per cent alumina fireclay (uncalcined) occurs as a parting between the Wall and Bench seams in the NCB Cross Tree Farm opencast coal site near Ewloe.

Since the Second World War the South Wales Coalfield has supported only a limited production of fireclay. In 1958 output was some 50,000 tonnes; but in recent years output has all but ceased.

The Lower and Middle Coal Measures are predominantly argillaceous and contain the thickest and most abundant coals and seatclays, whilst the Upper Coal Measures is mainly arenaceous, being dominated by the Pennant Sandstone, and has relatively few coals and seatclays. Opencast coal mining is largely concentrated in the upper part of the Lower Coal Measures and the lower and middle parts of the Middle Coal Measures where the more important coals occur. The coalfield consists of an east-west elongated basin and, as a result, opencast coal mining is confined to the periphery, and particularly to the northern crop where dips are shallower.

Fireclay mining was formerly concentrated in two areas. In the Pontypool area in the east, production was based on several fireclays in the Lower and Middle Coal Measures, whereas in the south-western part of the coalfield, in the Llanelli district, production was derived from the Upper Coal Measures. The last mine in the Pontypool area, working the fireclays below the Two-Feet-Nine coal and the Aegiranum (Cefn Coed) Marine Band in the Middle Coal Measures, closed in the late-1960s. Very small scale production (25 per cent Al_2O_3, uncalcined) from the Upper Pennant Measures (Upper Coal Measures) continues near Llanelli.

Detailed studies suggest that within the Lower Coal Measures and the lower part of the Middle Coal Measures to the east of the Vale of Neath, the seatclays are mainly fine-grained with kaolinite and mica (illite) the dominant clay minerals. Within the Upper Coal Measures, however, there is an increase in illite and chlorite at the expense of kaolinite. Higher qualtiy fireclays would therefore be expected to occur lower in the sequence, although from the limited amount of analytical data available it appears that high quality fireclays with uncalcined alumina contents exceeding 30 per cent are rare.

No fireclays are currently recovered from opencast coal mines, although significant quantities were produced for ladle brick manufcture until 1976 from the Lower Coal Measures of the north-eastern part of the coalfield and the southern crop near Bridgend. The fireclay below the upper leaf (Old Rider) of the Five-Feet-Gellideg with an uncalcined alumina content of 30.6 per cent was the best quality, but most was obtained from below the Yard (20 to 26 per cent Al_2O_3), which is possibly the Lower Seven-Feet of the standard sequence. Many of the fireclays are very hard and, because of structural complexities and contamination by carbon and ironstone nodules, quality control was difficult.

Other coalfields

Coals and seatclays occur in the Upper Coal Measures of the Forest of Dean Coalfield and fireclays are produced mainly for buff brick manufacture. In the Somerset and Gloucestershire Coalfield there is at present no opencast coal production, but fireclay for buff brick manufacture is produced at Almondsbury from a brick clay quarry in the Lower and Middle Coal Measures.

Jurassic

In the Kingscliffe-Stamford area of Northamptonshire, Lincolnshire and Cambridgeshire, unbedded rootlet beds within the Upper Estuarine Series, consisting of greyish-white and brown silty clays, are worked for refractory applications. Although described as 'fireclays', because of their high silica content they are more akin to ganisters. Production is substantial, probably over 100,000 tonnes, mainly recorded as fireclay in official statistics. The fireclays are not associated with coals, although carbonaceous shales sometimes occur, but were deposited in a shallow water, deltaic or coastal plain environment.

The deposits are some 3 m thick and are highly siliceous, containing 70 to 80 per cent in the silt fraction, which consists mainly of quartz, although some clay minerals overlap into the finer silt sizes. The clay fraction consists of a mixture of interstratified montmorillonite-vermiculite, kaolinite and, possibly a degraded mica.

Table 16 Typical chemical analyses of siliceous fireclays from the Upper Estuarine Series, Middle Jurassic

	Wt %			
	1	*2*	*3*	*4*
SiO_2	84.6	79.2	79.03	73.98
Al_2O_3	7.42	10.5	10.97	13.53
Fe_2O_3	1.52	1.43	1.95	1.55
CaO	0.28	0.30	0.52	0.45
MgO	0.15	0.23	0.35	0.46
Na_2O	0.05	<0.01	0.20	0.19
K_2O	0.30	0.52	0.26	0.61
TiO_2	2.19	2.48	2.11	1.90
Loss on ignition	3.12	4.62	4.56	6.43

Source: 1 Silty clay. Kingscliffe. Kingscliffe Super Refractories Ltd.
2 Silty Clay. Kingscliffe. The Nene Barge and Lighter Co Ltd.
3 'White' silty clay. Stamford. Williamson Cliff Ltd
4 'Brown' silty clay. Stamford. Williamson Cliff Ltd.

The fireclays are used in the manufacture of hand-made facing bricks and for refractory applications, such as siliceous patching and ramming materials for cupola furnaces and ladles. Minor quantities are used in the pottery industry.

Long term availability

Fireclays, as seatclays, are widely distributed throughout most coalfields and occur over considerable stratigraphical thicknesses of strata. Total resources are extremely large. Consequently, fireclay resources have sometimes been described as "inexhaustible" and certainly in most areas in which working has declined or ceased it has not been through any lack of material in the ground, but because of the high cost of underground mining and falling demand for specific applications. However, any estimate of total resource needs considerable qualification. Fireclays exhibit a broad spectrum of compositions and properties and many are not interchangeable in end-use. For example, even relatively minor increases in carbon, sulphur or iron contents may make a prospective fireclay totally unacceptable for ceramic applications. Whilst British Standard and other specifications cover many of the products that are manufactured from fireclays, no such precise specifications exist for the raw material and many companies may have their own requirements. Consequently fireclay acceptable to one company may be of no, or only limited value to another. Resources of specific grades of fireclay have an uneven distribution and may be limited at local or even regional level, as is the case with buff-firing fireclays, for which delivered price is particularly important, and also aluminous (< 40 per cent Al_2O_3, calcined) fireclays, which are almost entirely confined to central Scotland. The complete range of qualities do not therefore occur in any one area. No assessment of resources can be undertaken without due regard for the physico-chemical properties of, and patterns of demand for, different fireclays. Detailed drilling and clay evaluation are required on a site by site basis in the same way as opencast coal reserves are assessed. Although detailed information is available for only a few selected sites, an indication of the likely reserves in most deposits becomes apparent only as the site is worked. Experience has shown that because of variations in quality, particularly due to the presence of impurities, and the need, therefore, for highly selective mining, there is a tendency to overestimate the likely yield.

The close association of coal and fireclay means that fireclay can be produced as a low cost by-product of opencast coal mining and, with a few notable exceptions, principally the refractory fireclays of the Passage Group in central Scotland, the extraction of most fireclay would not be economically viable without associated coal. A return to high cost, underground methods of mining is therefore highly unlikely, since this would remove one of the main advantages of fireclays, their low price, and depress demand even further. Opencast coal mining has thus made available fireclays which would not otherwwise have been economically recoverable. Potential sources of fireclay, therefore, occur in most of the exposed coalfields where opencast coal mining is being undertaken (Fig. 14), although this does not imply that fireclays occur either in all, or even most, opencast coal mines. However, the national capacity to produce the mineral far exceeds demand and consequently, even where fireclay does occur, it is often not worked, recovery being confined to a limited number of operations. Seatclay, including potentially marketable fireclay, is backfilled with the overburden and thus irrecoverable. Paradoxically,

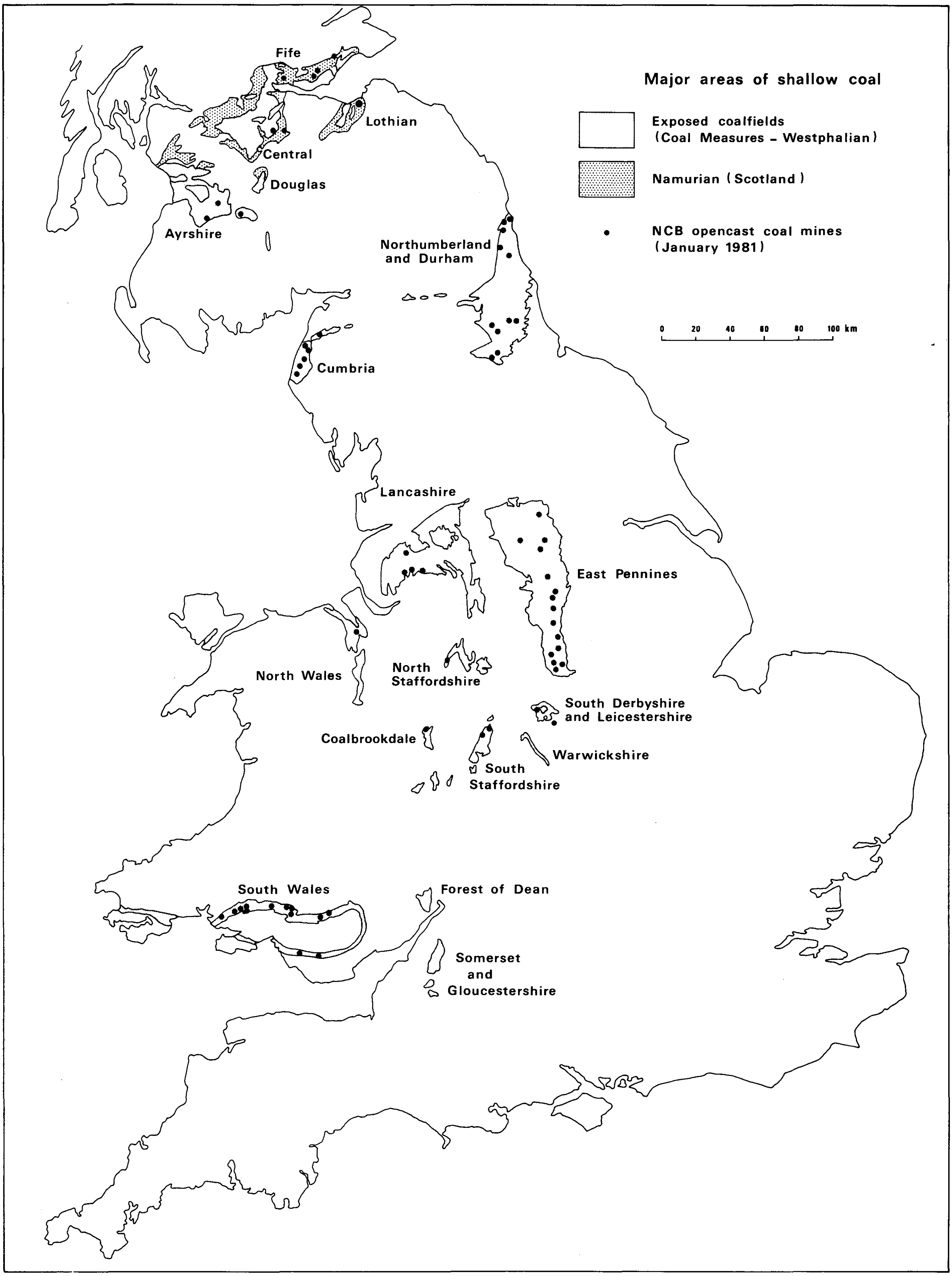

Fig 14 Exposed coalfields in Great Britain and distribution of NCB opencast coal mines.

therefore, the opencast coal industry has had the effect of both increasing reserves of fireclay and depleting national resources by backfilling, principally because of insufficient demand. In the face of declining demand, current supplies of fireclay are more than adequate. However, the loss of fireclay resources associated with opencast coal working is very real, although it is difficult to assess its importance in the longer term.

Stockpiling has been advocated to conserve fireclays: some consumers have built up large stocks when fireclays were cheaply and locally available and there are large producer stockpiles in the South Derbyshire, Coalbrookdale and South Staffordshire coalfields. Stockpiles provide continuity of supply from an established source and by facilitating blending, allow a more consistent raw material to be supplied. However, they may give rise to considerable environmental and financial problems associated with their location and funding. Controlled storage below restoration levels may overcome some of the environmental problems and is used at Donington Extension, but at most sites would inevitably incur higher costs.

Although there is no direct relationship between opencast coal and fireclay reserves, because of the more restricted distribution of the latter, the future supply of fireclay will be dependent upon opencast coal mining. The estimated reserves of coal workable by opencast methods (Table 17), include those measured (proved by drilling), indicated (limited amount of borehole information) and inferred (little or no sampling): about half is measured and indicated.

Table 17 Coal reserves workable by opencast methods (March 1980)

Coalfield	*Million tonnes*
Scottish	90
Northumberland and Durham	195
West Cumbria	20
Lancashire	15
North Wales	10
North Staffordshire	10
Cannock and South Staffordshire	35
Warwickshire	45
Shropshire (Coalbrookdale)	minimal
Yorkshire, Derbyshire and Nottinghamshire	90
South Derbyshire—Leicestershire	45
South Wales	45
TOTAL	600

Source: National Coal Board Opencast Executive.

Reserves are, therefore, sufficient to sustain opencast coal production at current levels well into the next century. This is not to say that opencast coal mining will always, or even often, coincide with fireclays of the desired quality, because of the uneven geographical and geological distribution of particular grades. Moreover, the future life of the opencast coal industry will be influenced by many factors other than reserves of coal; for example, environmental problems are of particular concern in certain sectors. Despite the uncertainities, however, it seems likely that viewed nationally, adequate fireclay supplies will be available from opencast coal mines for many years. Any curtailment of the opencast coal programme might well extend the life of fireclay reserves, provided that the coal is ultimately worked.

Opencast coal mining

The advent of opencast coal mining during the Second World War provided an alternative source of fireclay, which until then had been predominantly won by underground mining. The importance of this source has increased in post-war years and general information on the opencast coal industry is a useful background to a discussion of its role in the production of fireclay.

Although opencast coal production was initiated as a temporary emergency measure, production has continued and totalled some 390 million tonnes in the period 1942 to 1980 (Fig 15). Responsibility for opencast coal mining passed from the Ministry of Works to the Ministry of Fuel and Power in 1945 and to the National Coal Board in 1952. Production remained at a high level during the coal shortages of the post-war years (Fig 15), but in the 1960s, when coal supply exceeded demand, output rapidly declined. Production rose again in response to the 1973 energy crisis and in the National Coal Board's 'Plan for Coal', endorsed by the Government in 1974, it was proposed that coal output be raised to at least 135 million tonnes by 1985, including an increase in opencast coal output from 10 to 15 million tonnes a year. Despite a lower demand for coal than forecast, the target of 15 million tonnes was achieved in 1980 when opencast production represented 12 per cent of total output, the highest proportion yet achieved.

Opencast coal mining is highly profitable and makes a significant contribution to the viability of the whole industry by counterbalancing the losses resulting from high cost deep mining. It requires much less capital outlay and less manpower than deep mining, and sites can be opened and worked with only temporary disruption to the landscape, the average site lasting about 4 years, the range being 2 to 12 years, although extensions and adjacent sites can greatly prolong activity in any particular area. Opencast coal is usually of a high quality and by blending with deep mined coal with higher ash contents, it can be used to improve overall grades. Although the boundaries of opencast mines are limited by roads, railways, built-up areas, and overburden ratios, within the area worked, a high proportion of the coal in place is recovered, from seams as thin as 0.08 to 0.1 m (if of adequate quality). Most of the coal produced by opencast mining could not be recovered by deep mining and, in addition, voids created by opencast mining can be used for colliery spoil disposal where close to deep mining operations. Opencast coal represents an economically attractive and easily accessible source of energy, therefore. Originally overburden to coal ratios were small and early sites were shallow, but the increasing size of heavy earthmoving equipment and the rising price of coal has allowed greatly increased ratios, which may now be up to 25 to 1 for bituminous coal and over 30 to 1 for anthracite: the average is about 18 to 1. Sites are consequently becoming much deeper and some areas have been re-worked, sometimes on more than one occasion,to obtain deeper coals. To sustain an output of 15 million tonnes annually, some 2,000 hectares a year have to be brought into production and some 8,000 hectares are in production at any one time.

As the scale of most workings can make a significant impact on the environment, oppositon to opencast coal mining has grown. However, some opencast coal mines serve the dual purpose of providing both low cost coal and improvements to the environment by being linked to land reclamation schemes. Planning decisions related to production by the NCB Opencast Executive are subject to the Opencast Coal Act 1958 and, unlike those relating to other minerals, are made at national level. Authorisation to work, subject to working and restoration conditions, can be granted by the Secretary of State for Energy unless objections are received within 28 days of publication of the proposal. The Department of Energy has a statutory duty to hold a public inquiry if there are objections from the local planning authorities, or anyone with a legal interest in the land. Once authorisation is completed tender documents are submitted to the Board's contractors giving the details of the geology, tonnage of coal present in the site, the volume of overburden, restrictions on working and restoration conditions. Contractors tender on the basis of the delivered price per tonne of coal supplied to the NCB, which will vary from site to site, the differences depending mainly on the overburden ratio. It is now customary for the Board's contractors to be asked also to tender for fireclay extraction, but contracts specify that this should not interfere with coal production.

Except for alienated coal, that is coal not owned by the NCB (of which very little remains to be worked), the ownership of coal is vested with the National Coal Board, from which others who wish to work it must obtain a licence. By Section 36 of the Coal Industry Nationalisation Act, 1946, as amended by Section 46 of the Opencast Coal Act, 1958, the categories to which licences apply are:

- 36(a) Coal dug or carried away in the course of activities other than mining, e.g. the digging of foundations, roads, canals and pipelines.
- 36(2)(a) Underground mining of coal where the number of persons employed below ground "is not likely to exceed, or greatly exceed, thirty".
- 36(2)(b) Coal worked as an ancillary to other minerals e.g. fireclay (normally only granted if the value of the ancillary mineral far exceeds the coal value).
- 36(2)(c) The coal to be taken is "not likely to exceed, or greatly to exceed, 25,000 tonnes" in total.

The licensee must pay either a royalty, regardless of coal quality (the maximum royalty was approximately £15 a tonne in 1980 although it will increase if the price of coal rises) or deliver the coal to an NCB disposal point for an agreed price per tonne. New licences tend to be given on the

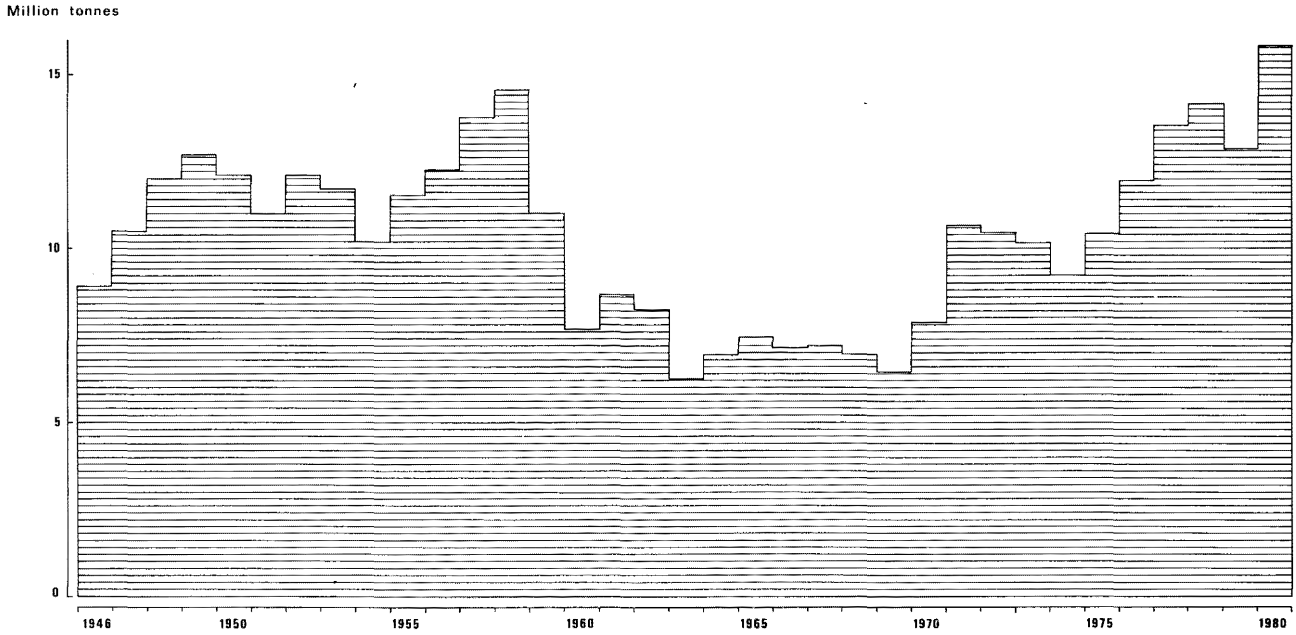

Fig 15 United Kingdom: Opencast coal production, 1964-1980

latter basis. Since for most operations the value of the ancillary mineral is unlikely to greatly exceed the value of coal, most new licences are under Section 36(2)(c). They are therefore restricted in size. As the NCB does not award a succession of licences to cover adjacent areas, the capacity for a licensed operator to produce clay (either fireclay or shale) is limited. Private operators claim that licences are becoming increasingly difficult to obtain. Planning decisions relating to private opencast working are considered by the local authority. Production from licensed sites compared with the total is shown in Table 18, which indicates that licensed sites apparently account for only a very small proportion of

Table 18 United Kingdom: Opencast coal production, 1974-1980

	Thousand tonnes		
	Licensed sites	*NCB sites*	*Total*
1974	452	8,814	9,266
1975	321	10,064	10,385
1976	338	11,606	11,944
1977	420	13,131	13,551
1978	265	13,902	14,167
1979	315	12,548	12,862
1980	537	15,242	15,779
1981	466	14,362	14,828

Source: Department of Energy

national opencast coal production. However, the production figures for coal from licensed sites is thought to include only coal on which a royalty has been paid and not that delivered to NCB disposal points, and thus the total contribution made by the private opencast coal industry is probably in excess of 1 million tonnes.

During 1980/81 the NCB Opencast Executive recorded a profit of £156.5 million on a turnover of £436.7 million, of which total sales of fireclay probably accounted for less than £0.5 million. The average value of the coal was £34.22 a tonne (yielding a profit of £10.24 a tonne) compared with an average ex-pit price of fireclay of only some £3 a tonne. The ex-pit price of fireclay ranges from about £2 up to £12 a tonne for aluminous Scottish fireclay from the Passage Group.

Technology

Mining

Fireclays are produced by both underground and opencast mining. Before the Second World War, and for a period after it, most fireclays were still produced by underground mining, but the advent of opencast coal mining and the introduction of large earthmoving equipment made fireclays available at lower cost and, together with a declining demand for the mineral in many of its traditional applications, mine closures took place on a large scale. Over 200 fireclays mines were in operation after the Second World War; the more recent decline in numbers is shown in Fig 16. The adverse economics of operating underground mines is reflected by the sharp fall in numbers in the period 1979–81. Underground mining is now confined to the extraction of the more valuable highly refractory fireclays; 3 mines were in operation in England in 1981, the remainder working the thicker fireclays of the Passage Group in Scotland (Table 19). A further reduction in the number of mines seems likely over the next few years and no return to underground mining is envisaged in the forseeable future. Large resources of fireclay occurring at depth, and particularly where not associated with coal, will, therefore, remain economically unworkable.

Underground mining is by room and pillar methods (or room and stoop in Scottish mining parlance), seam thicknesses generally varying between 0.7 m and 2.5 m, the thickest seams being associated with the Lower Fireclays of the Passage Group of Scotland. Fireclays are hard and require blasting. They are then either hand or mechanically loaded into rail cars for rope haulage to the surface. The use of mechanical shearers has been attempted at one Scottish mine, but was found to be unsatisfactory because of the very hard nature of the fireclay. Selective mining is practised at some mines to obtain more than one grade; workable coal does not occur with the refractory fireclays currently mined.

The close geological association of fireclay and coal has meant that fireclay is increasingly being won by opencast methods and a major proportion of United Kingdom fireclay production is derived from opencast coal mines, both authorised NCB sites and licensed sites. However, some fireclays won by opencast methods are not associated with economically important coals; the Passage Group fireclays of central Scotland and the highly siliceous Jurassic fireclays of the Midlands are examples. The scale of opencast fireclay working is very variable ranging from small fireclay quarries producing several hundred tonnes a year to

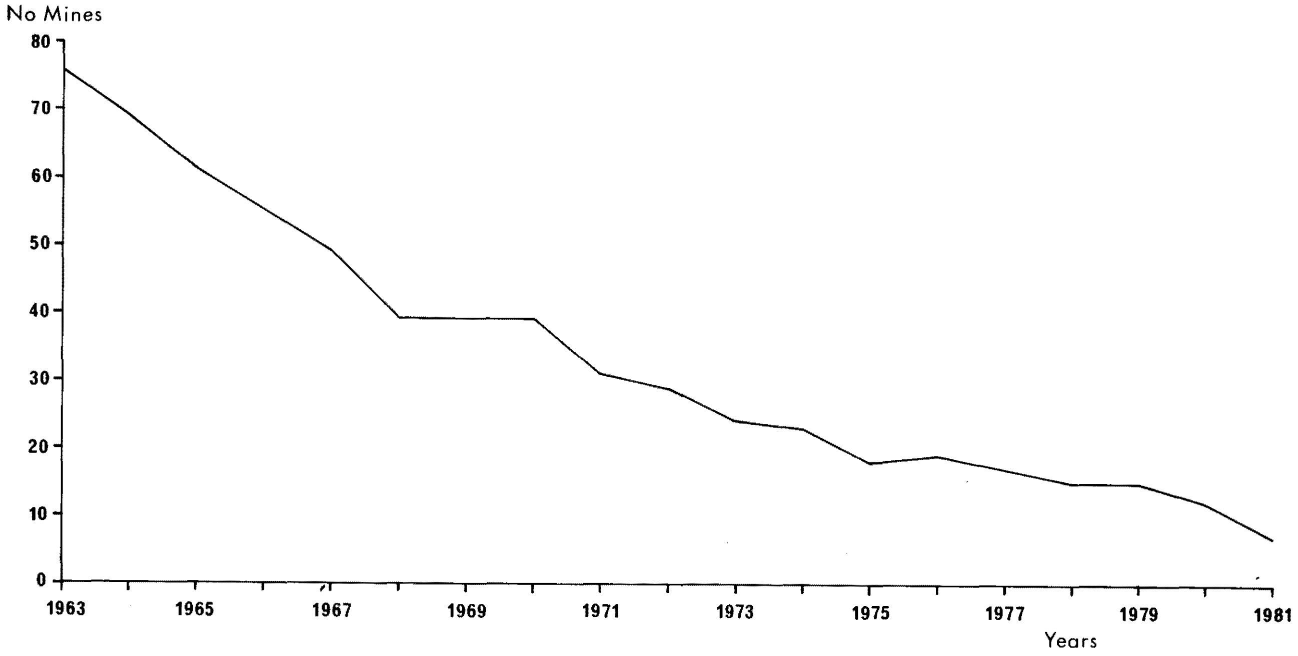

Fig 16 Number of underground fireclay mines in the United Kingdom, 1963-1981

Table 19 Operating underground fireclay mines in the United Kingdom, 1981

Name	*Operator*	*Geological Horizon*	*Location*
Ballencrieff	The Burn Fireclay Co Ltd	Lower Fireclays, Passage Group	Bathgate, Lothian Region
Pottishaw	United Fireclay Products Ltd	Lower Fireclays, Passage Group	Bathgate, Lothian Region
Wallhouse	GR-Stein Refractories Ltd	Lower Fireclays, Passage Group	Torphichen, Lothian Region
Carbrook	Craigend Refractories Ltd	Lower Fireclays, Passage Group	Denny, Central Region
Storrs Bridge	Thomas Marshall & Co (Loxley) Ltd	Pot Clay, Lower Coal Measures	Loxley, South Yorkshire
Shibden No. 2	Parkinson-Spencer Refractories Ltd	Halifax Hard Bed, Lower Coal Measures	Halifax, West Yorkshire
Park Nook	Samuel Wilkinson & Sons Ltd	36 Yard, Lower Coal Measures	Halifax, West Yorkshire

large opencast coal mines generally producing up to about 50,000 tonnes of fireclay a year. The Donington Extension site in the South Derbyshire Coalfield with an output of about 1.0 million tonnes of fireclay a year is exceptional. Working methods also vary in consequence, but for the majority of authorised opencast coal mines the operation is basically the same.

At least 0.3 m of soil and up to 0.9 m of subsoil are stripped and stored as baffles to screen the site visually and cut down noise. Overburden removal is undertaken by digging a series of parallel box-cuts, material from the initial cut being stored on the surface. Overburden from each successive cut is cast into the void of the previous cut and progressive restoration is therefore undertaken. Overburden may be removed by draglines, scrapers and truck and shovel, or a combination of all three, removal by dragline being the cheapest method. Coal is extracted by small rope or hydraulic crowd shovels, seam thicknesses of down to 0.08 m being mineable provided the coal parts adequately from the associated sediments. Overburden to coal ratios are commonly up to 25 to 1 and even higher where anthracite is dug. With the increase in overburden to coal ratios, depths of 75 m are not uncommon (the average being 50 m), and one site is intended to reach more than 200 m. This trend is likely to continue as energy prices rise, although ultimately much depends on the extent of past underground mining activity and the areas available for mining.

The fireclays (except that beneath the lowest coal) form part of the overburden and have to be removed whether they are marketed or not. Overburden removal costs vary depending on the geological conditions and the type of equipment used, but with truck and shovel were of the order of 50 to 60 p/m^3 in 1980. Fireclay is extracted in a manner similar to coal although where of a reasonable thickness rippers and scrapers are used. Fireclays are not so easily distinguished by their colour as coal and are also much more variable in quality. The presence of ironstone and pyrite nodules and carbonaceous bands may demand a high degree of selective mining, requiring considerable care and continuous monitoring if contamination and wastage is to be prevented.

There are therefore additional costs to the production of fireclay over and above normal overburden stripping costs, because of the need for selective extraction, loading and transport to temporary stock. Costs can be further increased if the fireclay does not directly underlie a workable coal seam, necessitating three lifts (strata above the bed, the fireclay and the strata to the next coal) rather than one if regarded as overburden. Depending on geological conditions, it is possible to work fireclays down to 0.3 m in thickness. The fireclays are stocked on site by individual bed or part of bed from which customers can be supplied directly. However, layered stockpiling techniques have been developed by some of the larger fireclay consumers to overcome variations in quality. Thin layers of different fireclays 0.15 m thick are laid down in a predetermined fashion to produce a multi-layered ‘sandwich’ up to 30 layers thick. Scrapers then gather across the cross-section of the stockpile and produce a further stockpile again put down in layers. This layered stockpile is mixed vertically with a bottom emptying face shovel and the final blend fed directly to the plant. This technique is widely used by the fireclay consumers in the South Derbyshire Coalfield to produce predictable and consistent feeds.

Processing and manufacture

Fireclays used in the manufacture of refractories, pipes and facing bricks undergo little processing other than blending and grinding prior to shaping and firing. Blending is undertaken to produce both consistent feeds and, by using different grades, to alter the physico-chemical properties of the raw material to increase (or lower), for example, refractoriness. In the case of buff facing bricks, blending is undertaken to produce a range of fired colours. For refractory production, ironstone nodules are sometimes screened out and electromagnetic separators have been used to reduce iron levels by removing siderite. However, where fireclay is used in the manufacture of pottery bodies such as stoneware, sanitaryware and floor and wall tiles, the clay is converted to a slip using blungers (a machine for mixing clay to produce a slip) or ball mills and is sieved to remove oversize material. Electromagnets remove any tramp iron. The presence of hard lumps of fireclay and ironstone nodules can be a problem where high speed blungers are used necessitating careful selection of clay. In the case of tile production the clay slip is spray dried and the tile produced by dust pressing. In stoneware pottery manufacture the clay slip is filter pressed and pugged for use in traditional hand shaping or machine forming. Sanitary fireclayware is produced by slip casting.

Fireclay bricks and shapes are produced by dry pressing, stiff plastic pressing or extrusion followed by repressing. Some complicated shapes are hand moulded. Dry pressing allows fireclays with lower moisture contents to be used, giving bricks with lower drying shrinkage and better dimensional tolerances. Mechanical pressing is used to achieve high bulk densities. Grog additions vary from 5 up to 70 per cent for more complicated shapes where dimensional accuracy is critical. Grog or waste firebrick from the demolition of furnaces is currently plentiful because of steel plant closures, but will eventually become scarce and with better control of firing conditions less 'in house' wastage is produced. Specially calcined clays or chamottes are therefore used as a substitute, but are relatively expensive, due to energy costs. Chamottes are produced in shaft calciners and rotary kilns and lightweight refractory aggregates are produced on sinterstrands.

The firing of refractory bricks and shapes is carried out in both intermittent and continuous kilns. Tunnel kilns, in which the firing zone remains stationary and the unfired product moves progressively through the firing zone, have been introduced at most modern factories, although continuous chamber kilns in which the firing zone moves from chamber to chamber around the kiln are still widely used. Firing cycles range from two days for tunnel kilns up to 3 to 4 weeks for continuous chamber kilns. Firing temperatures range from 1,110°C for bloating ladle bricks to 1,500°C for Scottish aluminous firebricks; most English fireclays achieve their maximum density between 1,100 and 1,200°C. An oxidation period at between 600°C to 900°C is of critical importance in the firing of fireclays to allow carbonaceous matter to be burnt out to prevent black coring. The introduction of fast firing tunnel kilns has therefore had a limiting effect on the amount of carbon that can be tolerated.

Buff facing bricks are predominently produced by wire cut extrusion methods and treated to give a range of surface textures. A range of fired colours is made by using different fireclays and blending buff-firing fireclays and red-firing mudstones. Some buff facing bricks are made entirely from fireclay with the addition of manganese dioxide to impart a grey colour. Firing is almost always in tunnel kilns at temperatures of between 1,020 and 1,080°C, although maturing temperatures of 1,110 to 1,140°C are required for more refractory fireclays with an attendant increase in energy requirements. Again, problems arise with carbon levels and the use of oxygen to facilitate oxidation of carbon is being considered. Vitrified clay pipes are produced by extrusion and firing is carried out almost entirely in tunnel kilns although a few beehive kilns still remain.

With rising energy costs, however, there is a trend towards the use of faster-firing schedules aided by oxygen addition to improve kiln throughputs, and also the use of precalcined clays, which may allow very rapid firing.

Production and overseas trade

Production

Present (1980) production of 1.2 million tonnes is at the lowest level since records began in 1873 (Fig 17). Fireclay production has shown a declining trend since the early 1950s (Table 20), although some wider fluctuations about this trend may have arisen from difficulties in the collection of statistics, related to problems of nomenclature and the multiple end-uses of fireclay in the refractories and non-refractories fields. Total production of fireclay in the period 1873 to 1980 is estimated to be about 235 million tonnes.

Table 20 United Kingdom: Fireclay production, 1947-1980

Thousand tonnes

1947	2,175	1964	1,923
1948	2,238	1965	1,900
1949	2,332	1966	1,977
1950	2,309	1967	1,718
1951	2,581	1968	1,969
1952	2,832	1969	1,703
1953	2,786	1970	1,967
1954	2,564	1971	2,230
1955	2,493	1972	2,108
1956	2,624	1973	1,832
1957	2,481	1974	1,704
1958	2,215	1975	1,606
1959	2,108	1976	1,464
1960	2,194	1977	1,499
1961	2,218	1978	1,404
1962	1,918	1979	1,710
1963	1,712	1980	1,217

Sources: 1947-1972 Annual Abstract of Statistics, Central Statistical Office
1973-1980 Business Statistics Office

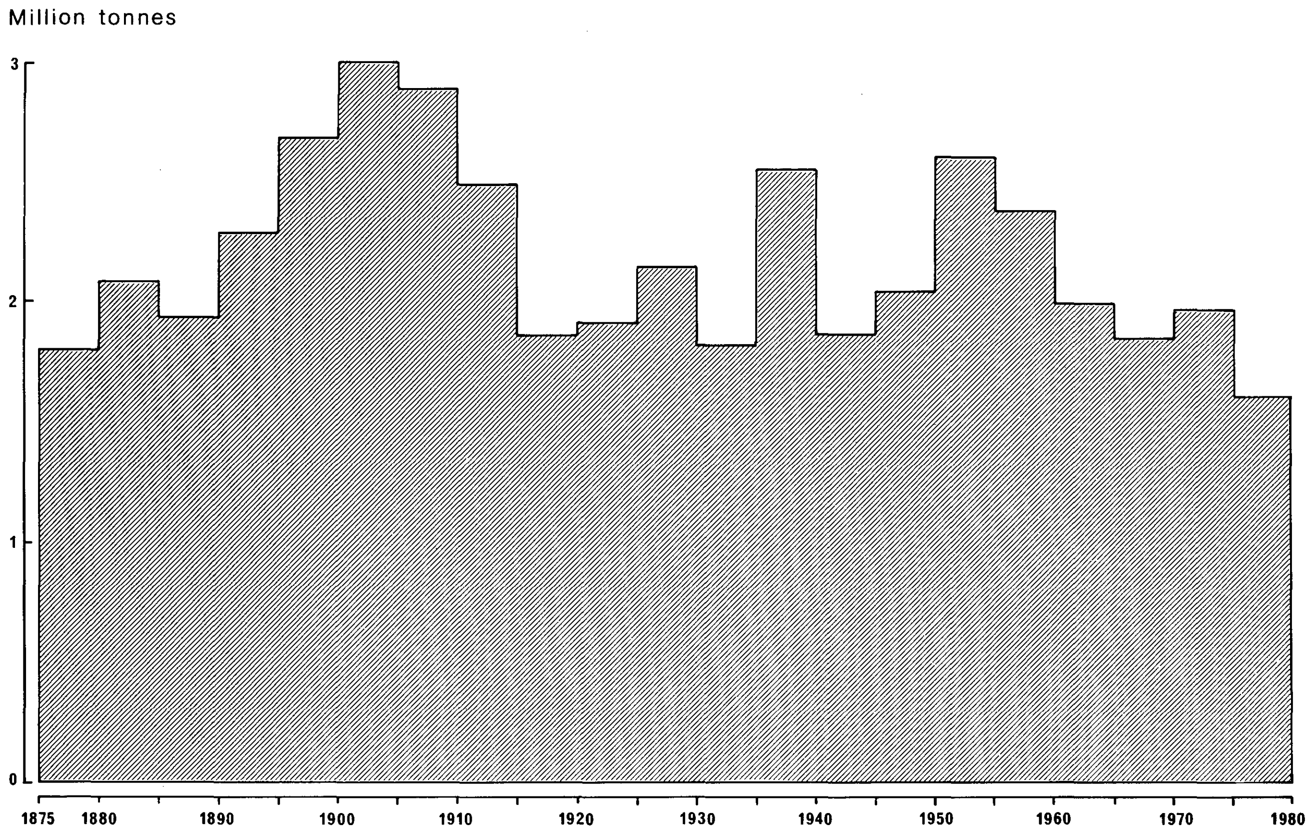

Fig 17 United Kingdom: Production of fireclay, 1875-1979 (5 years averages)

Production by end-use and region is shown in Table 21. Output is almost entirely confined to the coalfields, although highly siliceous clays from the Jurassic Upper Estuarine Series in Northamptonshire, Cambridgeshire and Lincolnshire are also included. The importance of the output from the South Derbyshire Coalfield in the East Midlands is clearly indicated.

Prior to the early 1920s, only fireclay production from underground mines registered under the Coal Mines Act was recorded; fireclay produced by quarrying was not recorded, although it seems unlikely that there was any significant production by opencast operations until the Second World War when opencast coal mining commenced. Over 80 per cent of total production is now obtained from opencast coal mines in both the public and private sectors, either as a co-product or by-product.

The opencast coal industry has expanded significantly in recent years: in January 1981 there were 62 authorised opencast coal mines operating in the United Kingdom, of which only nine produced fireclay; those situated in the South Derbyshire, Northumberland and Durham coalfields accounted for virtually the entire production. Normally, fireclay production is a fraction of coal ouptut, for example, at the Butterwell site in Northumberland fireclay production during the period mid-1977 to mid-1980 amounted to 36,000 tonnes, compared with over two million

Table 21 United Kingdom: Production and end-use of fireclay by Economic Planning Region, 1979

	Thousand tonnes			
Economic Planning Region	*Refractory purposes*	*Brick, pipes and tiles*	*Other purposes*	*Total*
Northern	n.a.	n.a.	—	128
Yorkshire and Humberside	88	12	—	100
East Midlands	322	601	—	923
East Anglia	2	—	—	2
West Midlands	129	12	—	141
North West	n.a.	n.a.	—	53
England	653	694	—	1,347
Wales	33	37	25	95
Scotland	260	—	8	268
Northern Ireland	—	—	—	—
United Kingdom	947	731	33	1,710

Source: Business Statistics Office
n.a. not available
— nil

tonnes of coal. There are exceptions, for example, the Esh Winning site in Durham has been one of the largest fireclay producers, some 250,000 tonnes having been extracted throughout its 3½ year life, compared with about 600,000 tonnes of coal. Current annual fireclay production from the Donington Extension site is approximately 1.0 million tonnes compared with about 0.5 million tonnes of coal.

Table 22 Fireclay sales from National Coal Board opencast coal mines, 1973-1980

Tonnes			
1973	148,128	1977	143,901
1974	91,586	1978	173,269
1975	121,695	1979	136,197
1976	141,267	1980	43,629

Sources: National Coal Board Opencast Executive
Whitfield Minerals Ltd.

Fireclay sales by the National Coal Board excluding the Donington Extension site is shown in Table 22. The sharp fall in sales during 1980 was due to declining demand and use of stocks.

In recent years, by far the major proportion of fireclay sales from authorised mines has been from the Northumberland and Durham coalfield, which provides local facing brick and refractory manufacturers with almost all their requirements.

Table 23 Fireclay sales from NCB opencast coal mines, 1978-1980 (a)

	Site	*Tonnes* 1978	1979	1980
Northumberland Coalfield	Butterwell	13,415	18,722	10,648
	Sisters	20,763	8,429	—
	St Andrews	5,594	9,458	10,909
Durham Coalfield	Esh Winning	39,226	84,376	6,669
	West Brandon	30,676	2,714	—
	Hunters	97	—	—
	Incline (b)	27,786	—	—
	Knitsley	3,004	10,344	—
	Biggin South	6,039	—	—
	Rowley	—	886	11,356
	Howard	—	—	76
	Buckhead	—	—	297
West Cumbria Coalfield	Outgang	927	1,011	1,373
	Mabel Plantation (b)	378	—	—
Shropshire (Coalbrookdale)	Brandlec (Stocking ground)	22,762	13,000	n.a.
Yorkshire Coalfield	Oxbow/Charcoal	2,602	—	—
South Staffordshire Coalfield	Kingswood	—	251	2,301
TOTAL		173,269	136,197	43,629

Source: National Coal Board Opencast Executive
(a) Excludes the large output at the Donington Extension site which is subject to a special agreement between the local fireclay mineral rights owners and the NCB.
(b) Red-firing mudstones for brick manufacture
n.a. not available.

Comparison with Table 24 demonstrates that there is no fireclay production from most opencast coal mines.

Fireclay marketed by the NCB (Table 23) through their distributors represents a comparatively small proportion of total fireclay production in the United Kingdom (Table 21), whilst fireclay obtained through joint extraction agreements between the NCB and the mineral rights owner has become of increasing importance in recent years. Within the private sector only a small proportion produce fireclay. Although statistics are not available it is estimated that production from licensed opencast coal mines

Table 24 NCB opencast coal production by coalfields, 1980

Coalfield	*Tonnes*
Scottish Coalfields	2,645,203
Northumberland	2,116,876
Durham	630,251
West Cumbria	549,551
Lancashire	312,437
North Wales	275,008
Shropshire (Coalbrookdale Coalfield)	148,379
South Staffordshire (Cannock)	1,046,153
North Staffordshire	206,145
Yorkshire	1,449,474
Nottinghamshire/North Derbyshire and South Derbyshire/Leicestershire	3,002,215
South Wales	2,569,984
TOTAL	14,951,676

Source: National Coal Board Opencast Executive

might be about 300,000 tonnes: a greater contribution to total fireclay production than NCB opencast coal mines, despite the fact that only a small proportion of the private mines produce fireclay. Most is derived from private fireclay producers particularly in the Coalbrookdale, South Derbyshire and South Staffordshire coalfields, rather than from licensed opencast coal mines with minor by-product fireclay.

Whilst not the subject of this dossier it should be noted that opencast coal mines also represent a very large potential source of red-firing shales and mudstones potentially suitable for use in the manufacture of facing and engineering bricks and vitrified clay pipes. A high carbon content is the main impurity likely to be encountered in these raw materials. Mudstones and shales command a low price and brick manufacturers usually operate their own quarries adjacent to brick works. However, increasing quantities are being bought on the open market.

Overseas trade

Imports and exports of fireclay refractory products are listed in the United Kingdom Tariff and Overseas Trade Classification for 1980 under the following code numbers:

2507 8020	Fireclay
2507 4000	Chamotte earth
6902 5100	Refractory bricks, blocks, tiles and similar refractory constructional goods containing more than 7 per cent but less than 45 per cent by weight of alumina (Al_2O_3)
6903 5100	Refractory holloware (e.g. retorts, nozzles, tubes, pipes, sheaths and rods), not elsewhere specified, containing less than 45 per cent by weight of alumina (Al_2O_3)

United Kingdom exports of fireclay have dropped substantially in recent years, from a peak of over 60,000 tonnes in 1952 to only 7,650 tonnes in 1980 valued at £480,00 (Fig 18). Exports of fireclay refractory constructional goods and fireclay refractory holloware to nearly seventy countries are currently worth over £9 million and £6 million respectively a year. The quantity and value of the exports of these goods during the period 1970 to 1980 are shown in Table 25.

Table 25 United Kingdom: Exports of fireclay refractory constructional goods, 1970-1980 and refractory holloware, 1977-1980

	Constructional goods		*Holloware*	
	Thousand tonnes	*Value (£ thousand)*	*Thousand tonnes*	*Value (£ thousand)*
1970	72.4	3,309	n.a.	n.a.
1971	75.7	3,586	n.a.	n.a.
1972	66.1	3,470	n.a.	n.a.
1973	67.4	4,808	n.a.	n.a.
1974	92.7	7,577	n.a.	n.a.
1975	105.6	11,420	n.a.	n.a.
1976	84.5	8,121	n.a.	n.a.
1977	77.9	7,387	8.6	2,961
1978	56.8	6,536	7.8	3,466
1979	74.2	9,297	9.6	4,828
1980	77.8	9,736	12.0	6,423

Source: H M Customs and Excise
n.a. not available

Exports of chamotte earth amounted to 321 tonnes in 1980 valued at £11,000.

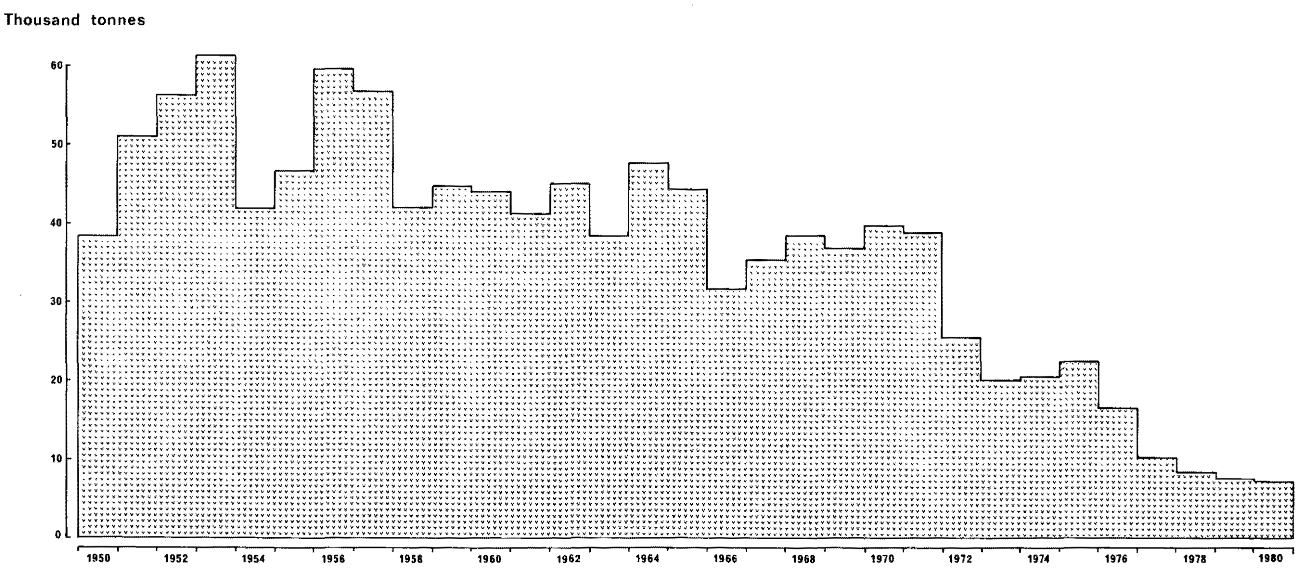

Fig 18 United Kingdom: Exports of fireclay, 1950-1980

Comparable figures for much smaller imports of fireclay, and fireclay refractory constructional goods are shown in Table 26. Imports of fireclay refractory holloware amounted to only 341 tonnes in 1980 valued at £220,000.

Table 26 United Kingdom: Imports of fireclay and fireclay refractory constructional goods, 1970-80

	Fireclay		*Constructional goods*	
	Thousand tonnes	*Value (£ thousand)*	*Thousand tonnes*	*Value (£ thousand)*
1970	5.4	140	15.7	2,273
1971	11.2	274	9.0	1,785
1972	9.8	230	5.9	1,221
1973	10.1	248	10.4	2,163
1974	9.7	379	6.3	1,955
1975	8.1	351	3.8	993
1976	4.5	268	4.5	1,717
1977	5.7	327	4.6	991
1978	4.1	291	1.5	365
1979	3.3	283	2.0	600
1980	4.8	438	2.6	557

Source: H.M. Customs & Excise.

Imports of chamotte earth, probably flint clay, amounted to 20,718 tonnes in 1980 valued at £1,373,000, the major sources of supply being France and South Africa.

Industry

Over 90 per cent of consumption of fireclay in the United Kingdom is accounted for by the refractory, vitrified clay pipe and facing brick manufacturing industries, which are represented by The National Federation of Clay Industries Ltd. Small quantities of fireclay are consumed by the pottery industry.

The structure of the fireclay industry in the United Kingdom has changed dramatically since the Second World War, particularly during the last 20 years or so. Formerly there was a large number of relatively small producers scattered throughout the coalfields extracting fireclay, often by underground mining, principally for their own use in the manufacture of refractory goods and salt-glazed pipes and sanitaryware. A decline in demand for fireclay in its traditional markets, rationalisation within the industry through closures, mergers and takeovers, and a swing away from underground mining to opencast extraction has very substantially reduced the number of producers, and consumers have become increasingly dependent on non-captive sources of supply, that is, from opencast coal mines. This is particularly well illustrated by the clay drainage pipe industry. In 1953 there were over eighty manufacturers of salt-glazed pipes distributed throughout the coalfields, many of whom both produced and used fireclay as their basic raw material. Vitrified clay pipes have now almost totally replaced salt-glazed pipes and the number of sanitary pipe manufacturers has declined to less than five; they are dominated by the Hepworth Iron Co Ltd, a member of the Hepworth Ceramic Holdings Group, the only other significant producer being Naylor Bros. (Clayware) Ltd. The formerly widely dispersed industry is now concentrated in two areas, the South Derbyshire Coalfield and the Penistone area of South and West Yorkshire. Although fireclay is not a prerequisite for vitrified clay pipe production, it represents a very large tonnage application, and the Hepworth Iron Co Ltd is the largest single consumer of fireclay in the country. The operations of both the Hepworth Iron Co Ltd and Naylor Bros. (Clayware) Ltd in the Penistone area are based largely on local Lower Coal Measures mudstones although some fireclay is brought into the area. Opencast coal mines in both South and West Yorkshire offer potential sources of mudstone and fireclay for vitrified clay pipe production, if of suitable quality and within economic distance of manufacturing plant. The smaller producers of sanitary pipes currently rely on bought in raw materials.

Table 27 Refractory manufacturing companies which also produce fireclay

Company	*Product*	*Source*
GR-Stein Refractories Ltd (Hepworth Ceramic Holdings Group)	Aluminous firebricks	Passage Group, Scotland
Dyson Refractories Ltd (Dyson Group)	Aluminous firebricks, casting pit refractories and ladle bricks	Passage Group and Lower Coal Measures of Scotland. Pottery Clays Formation, Derbyshire
United Fireclay Products Ltd (Steetley Group)	Aluminous firebricks	Passage Group, Scotland
Thomas Marshall & Co (Loxley) Ltd	Casting pit refractories	Lower Coal Measures, South Yorkshire
Samuel Wilkinson & Sons Ltd	Firebricks	Lower Coal Measures, West Yorkshire
Coalmoor Refractories Ltd	Ladle bricks	Lower Coal Measures, Shropshire
The Burn Fireclay Co Ltd	Firebricks	Passage Group, Scotland
Craigend Refractories Ltd	Aluminous firebricks	Passage Group, Scotland
Parkinson & Spencer Ltd	Glasshouse pots	Lower Coal Measures, West Yorkshire
Williamson Cliff Ltd	Siliceous gunning mixes	Middle Jurassic, Stamford
Kingscliffe Super Refractories Ltd (subsidiary of Ticton Ltd)	Siliceous gunning mixes	Middle Jurassic, Kingscliffe

There has been a similar, although not so dramatic, rationalisation with the fireclay refractory industry with a substantial reduction in the number of manufacturers. There is currently overcapacity in the industry and the number will continue to decline. The majority have access to all or part of their raw material requirements and some sell fireclay on the open market.

The use of fireclay in the manufacture of buff facing bricks is a relatively recent application. Buff or light-firing fireclays occur in some of the Coal Measures sequences worked at a limited number of brickworks, but most is bought on the open market from opencast coal mines in both the public and private sectors. For most of the other uses of fireclay, that is in the pottery industry and for non-ceramic applications, it is bought on the open market.

Whitfield Minerals Ltd are the sole distributors of fireclay for the NCB. Castle Clay Sales Ltd and Thomas Wragg and Sons Ltd are the main companies marketing fireclays (as well as other clays) on behalf of the licensed opencast coal industry, which is also represented by Whitfield Minerals Ltd. Thomas Wragg and Sons Ltd have a majority interest in the Donington Extension Minerals Consortium which includes Dyson Refractories Ltd, Ellistown Pipes Ltd (part of the Hepworth Ceramic Holdings Group) and Redbank Manufacturing Co Ltd. Castle Clay Sales Ltd, through the Willesley Clay Co Ltd, also have access to substantial supplies of fireclay from a licensed opencast coal mine in the South Derbyshire Coalfield. Other private fireclay suppliers with access to fireclays within their own control are Coalmoor Refractories Ltd in the Coalbrookdale Coalfield and Potclays Ltd in the South Staffordshire Coalfield. The marked decline in the number of fireclay producing operations in the United Kingdom over the past twenty-five years has limited the choice of clays available on the market.

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Printed in England for Her Majesty's Stationery Office
by Hobbs the Printers of Southampton
(172) Dd716986 C9 6/82 G381

Mineral Dossier No 24: Fireclay

Mineral Resources Consultative Committee

ISBN 0 11 512102 1

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Department of Industry
July 1982

London: Her Majesty's Stationery Office